NUCLEAR DIVISION

REPORT NO. RN-S-0350

To

AEC-NASA Space Nuclear Propulsion Office
OPERATING & MAINTENANCE INSTRUCTIONS FOR
XE-1 TEST STAND CONTROL SYSTEM (TSCS)
TEST SIMULATION SUBSYSTEM

NERVA Program

Contract SNP-1

November 1968

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OPERATING & MAINTENANCE INSTRUCTIONS FOR
XE-1 TEST STAND CONTROL SYSTEM (TSCS)
TEST SIMULATION SUBSYSTEM

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TEST SIMULATION SUBSYSTEM

TSS SYSTEM FAILURE TABLE - ENGINE SYSTEM

Item	Failure	Probable Cause	Corrective Action
1.	TPCV meter on CTE console reads zero	1. (a) Improper patching (b) No TPCV demand to TSS (c) TPCV demand to TSS but no measured response	1. (a) Check analog patchboard C1 to S2; N1 to R1. (b) If no voltage on Modulok 49-TB2-37D or 60-TB2-49D, check upstream of TSS. (c) If patching in (a) above is okay, look for a bad amplifier in TPCV group. If A6203 reads a voltage, check Mod 60-TB2-49C and 49-TB2-37C for the same voltage. If they read properly then the problem is external to TSS.
2.	Drum position indicator on ATE panel reads zero	2. (a) Improper patching (b) No drum demand to TSS (c) Drum demand to TSS but no measured response	2. (a) Check analog patchboard; S5 to C2; Q2 to R2. (b) If no voltage on Modulok 60-TB2-46D or 48-TB2-104D, check upstream of TSS. (c) If patching in (a) above is okay, look for a bad amplifier in the drum group. If A6206 reads a voltage, check Modulok 60-TB2-58D and 48-TB2-105D for the same voltage. If they read properly, then the problem is external to TSS.
3.	Turbine inlet pressure meter reads zero under normal engine run conditions	3. (a) Improper patching (b) Signal not being generated (c) Bad interface connection	3. (a) Check analog patchboard R3 to N17. (b) Check A6135 for output. If it reads out, check N17 for output. No output here indicates bad circuit between A6135 and N17. (c) Read voltage output on Modulok 60-TB2-60D and 67-TB8-30D. If they read properly, problem is external to TSS.
4.	Tie rod temperature meter on ATE panel reads zero under normal engine run conditions	4. (a) Improper patching (b) Signal not being generated (c) Bad interface connection	4. (a) Check analog patchboard; M15 to R5. (b) Check Amp. 6119 for output. If no output, check tie rod simulation. (c) Read voltage output on Modulok 60-TB2-53D and 63-TB2-86D. If they read properly, problem is external to TSS.

TSS System Failure Table - Engine System (cont.)

Item	Failure	Probable Cause		Corrective Action	
5.	Chamber temp. meter on ATE panel reads zero under normal engine run conditions	5. (a)	Improper patching	5. (a)	Check analog patchboard; M16 to R6.
		(b)	Signal not being generated	(b)	Check Amp. 6112 for output. If no output, check T8 simulation.
		(c)	Bad interface connections	(c)	Read voltage output on Modulok 60-TB2-45D and 49-TB2-51D. If they read properly, problem is external to TSS.
6.	Engine log power meter on CTE & LRE panels reads zero during startup.	6. (a)	Improper patching	6. (a)	Check analog patchboard; Q8 to R8.
		(b)	Signal not being generated in TSS	(b)	Check Amp. 6256 for output. If no output, check log power simulation.
		(c)	Bad interface connection	(c)	Read voltage output on Modulok 60-TB2-55D and 47-TB1-113D. If they read properly, then problem is external to TSS.
7.	Test stand log power meter on LRE panel reads zero during startup	7. (a)	Improper patching	7. (a)	Check analog patchboard; P8 to R7.
		(b)	Signal not being generated in TSS	(b)	Check Amp. 6256 for output. If no output, check log power simulation.
		(c)	Bad interface connection	(c)	Read voltage output on Modulok 60-TB2-56D and 46-TB1-54D. If they read properly, then the problem is external to TSS.
8.	Log count rate meter on ATE console doesn't read during startup	8. (a)	Improper patching	8. (a)	Check analog patchboard; R9 to N9.
		(b)	Signal not being generated in TSS	(b)	Check Amp. 6255 for output. If no output, check log power simulation.
		(c)	Bad interface connection	(c)	Read voltage output on Modulok 60-TB2-65D and 09-128C. If they read properly, then the problem is external to TSS.
9.	Linear power (sawtooth) meter on CTE console reads zero during startup	9. (a)	Improper patching	9. (a)	Check analog patchboard; R10 to Q10.
		(b)	Signal not being generated in TSS	(b)	Check Amp. 6262 in nuclear instrumentation group. If no output, check log power generation.
		(c)	Bad interface connection	(c)	Read voltage output on Modulok 60-TB2-54D and 46-TB1-55D. If they read properly, then the problem is external to TSS.

TSS System Failure Table - Engine System (cont.)

Item	Failure	Probable Cause	Corrective Action
10.	Station 1/2 + 1 meter on ATE panel reads zero during startup	10. (a) Improper patching (b) Signal not being generated in TSS. (c) Bad interface	10. (a) Check analog patchboard; R15 to Q15. (b) Check Amp. 6101 for output. If no output, check core functional group simulation (c) Read voltage output on Modulok 60-TB2-63D and 63-TB2-84D. If they read properly, then problem is external to TSS.
11.	Cluster exit gas meter on ATE panel reads zero during startup	11. (a) Improper patching (b) Signal not being generated in TSS (c) Bad interface	11. (a) Check analog patchboard; R16 to Q16. (b) Check Amp. 6110 for output. If no output, check core functional group simulation. (c) Read voltage output on Modulok 60-TB2-64D and 63-TB2-85D. If they read properly, then problem is external to TSS.
12.	Tie rod meter on ATE panel reads zero during startup	12. (a) Improper patching (b) Signal not being generated in TSS (c) Bad interface	12. (a) Check analog patchboard; R5 to M15. (b) Check Amp. 6119 for output. If no output, check core group simulation. (c) Read voltage output on Modulok 60-TB2-53D and 63-TB2-86D. If they read properly, then problem is external to TSS.
13.	Station 20 meter on ATE panel reads zero during startup	13. (a) Improper patching (b) Signal not being generated in TSS (c) Bad interface	13. (a) Check analog patchboard; R16 to Q16. (b) Check Amp. 6110 for output. If no output, check core simulation. (c) Read voltage output on Modulok 60-TB2-44D and 63-TB2-88D. If they read properly, then problem is external to TSS.
14.	Turbine speed No. 1 meter on scram & bypass panel reads zero during startup	14. (a) Improper patching (b) Signal not being generated in TSS (c) Bad interface	14. (a) Check analog patchboard; R13 to N14. (b) Check Amp. 6294 for output. If no output, check pump simulation. (c) Read voltage output on Modulok 60-TB2-40D and 67-TB8-23D. If they read properly, then problem is external to TSS.

TSS System Failure Table - Engine System (cont.)

Item	Failure	Probable Cause	Corrective Action
15.	Turbine speed No. 2 meter on scram & bypass panel reads zero during startup	15. (a) Improper patching (b) Signal not being generated in TSS (c) Bad interface	15. (a) Check analog patchboard; R14 to M14. (b) Check Amp. 6294 for output. If no output, check pump simulation. (c) Read voltage output on Modulok 60-TB2-41D and 67-TB8-23D. If they read properly, then problem is external to TSS.
16.	LH ₂ flow meter on CTE panel reads zero during startup	16. (a) Improper patching (b) Signal not being generated in TSS (c) Bad interface	16. (a) Check analog patchboard; R21 to L24. (b) Check Amp. 6144 for output. If no output, check flow simulation. (c) Read voltage output on Modulok 60-TB2-59D and 67-TB8-29D. If they read properly, then problem is external to TSS.
17.	Turbine inlet temp. meter on CTE panel reads zero during startup	17. (a) Improper patching (b) Signal not being generated in TSS (c) Bad interface	17. (a) Check analog patchboard; R24 to K14. (b) Check Amp. 6295 for output. If no output, check flow simulation. (c) Read voltage output on Modulok 60-TB2-61D and 67-TB8-31D. If they read properly, then problem is external to TSS.
18.	Range Gen. Linear Pulse 0 meter on LRE panel reads zero during startup	18. (a) Improper patching (b) Signal not being generated in TSS (c) Bad interface	18. (a) Check logic patchboard; B33 to B34. (b) Check Amp. 6264 for output. If no output, check linear power range generator simulation. (c) Read voltage output on Modulok 60-TB2-89D and 46-TB1-58D. If they read properly, then problem is external to TSS.
19.	Range Generator Linear Pulse 1 meter on LRE panel reads zero during startup	19. (a) Improper patching. (b) Signal not being generated in TSS (c) Bad interface	19. (a) Check logic patchboard; C34 to C33. (b) Check Amp. 6264 for output. If no output, check linear power range gen. simulation. (c) Read voltage output on Modulok 60-TB2-89C and 46-TB1-58C. If they read properly, then problem is external to TSS.

TSS System Failure Table - Engine System (cont.)

Item	Failure	Probable Cause		Corrective Action	
20.	Range Gen. Linear Pulse 2 meter on LRE panel reads zero during startup	20. (a)	Improper patching	20. (a)	Check analog patchboard; D34 to D33.
		(b)	Signal not being generated in TSS	(b)	Check Amp. 6265 for output. If no output, check linear power range generator simulation.
		(c)	Bad interface	(c)	Read voltage output on Modulok 60-TB2-89B and 46-TB1-58B. If they read properly, then problem is external to TSS.
21.	Range Gen. Linear Pulse 3 meter on LRE panel reads zero during startup	21. (a)	Improper patching	21. (a)	Check analog patchboard; E34 to E33.
		(b)	Signal not being generated in TSS	(b)	Check Amp. 6266 for output. If no output, check linear power range generator simulation.
		(c)	Bad interface	(c)	Read voltage output on Modulok 60-TB2-89A and 46-TB1-58A. If they read properly, then problem is external to TSS.
22.	Range Gen. Linear Pulse 4 meter on LRE panel reads zero during startup	22. (a)	Improper patching	22. (a)	Check analog patchboard; F34 to F33.
		(b)	Signal not being generated in TSS	(b)	Check Amp. 6267 for output. If no output, check linear power range generator simulation.
		(c)	Bad interface	(c)	Read voltage output on Modulok 60-TB2-90D and 46-TB1-59D. If they read properly, then problem is external to TSS.
23.	Range Gen. Linear Pulse 5 meter on LRE panel reads zero during startup	23. (a)	Improper patching	23. (a)	Check analog patchboard; G34 to G33.
		(b)	Signal not being generated in TSS	(b)	Check Amp. 6268 for output. If no output, check linear power range generator simulation.
		(c)	Bad interface	(c)	Read voltage output on Modulok 60-TB2-90C and 46-TB1-59C. If they read properly, then problem is external to TSS.
24.	Range Gen. Linear Pulse 6 meter on LRE panel reads zero during startup	24. (a)	Improper patching	24. (a)	Check analog patchboard; H34 to H33.
		(b)	Signal not being generated in TSS	(b)	Check Amp. 6270 for output. If no output, check linear power range gen. generator simulation.
		(c)	Bad interface	(c)	Read voltage output on Modulok 60-TB2-90B and 46-TB1-59B. If they read properly, then problem is external to TSS.

TSS System Failure Table - Engine System (cont.)

Item	Failure	Probable Cause	Corrective Action
25.	Range Gen. Linear Pulse 7 meter on LRE panel reads zero during startup	25. (a) Improper patching (b) Signal not being generated in TSS (c) Bad interface	25. (a) Check analog patchboard; J34 to J33. (b) Check Amp. 6271 for output. If no output, check linear power range gen. simulation. (c) Read voltage output on Modulok 60-TB2-90A and 46-TB-59A. If they read properly, then problem is external to TSS.
26.	Range Gen. Linear Pulse 8 meter on LRE panel reads zero during startup	26. (a) Improper patching (b) Signal not being generated in TSS (c) Bad interface	26. (a) Check analog patchboard; K34 to K33. (b) Check Amp. 6272 for output. If no output, check linear power range gen. simulation. (c) Read voltage output on Modulok 60-TB2-91D and 46-TB1-60D. If they read properly, then problem is external to TSS.
27.	Range Gen. Linear Pulse 9 meter on LRE panel reads zero during startup	27. (a) Improper patching (b) Signal not being generated in TSS (c) Bad interface	27. (a) Check analog patchboard; L34 to L33. (b) Check Amp. 6273 for output. If no output, check linear power range gen. simulation. (c) Read voltage output on Modulok 60-TB2-91C and 46-TB1-60C. If they read properly, then problem is external to TSS.
28.	Station 26 meter on ATE panel reads zero during startup	28. (a) Improper patching (b) Signal not being generated in TSS (c) Bad interface	28. (a) Check analog patchboard; R17 to Q17. (b) Check Amp. 6100 for output. If no output, check core simulation. (c) Read voltage output on Modulok 60-TB2-42D and 48-TB2-102D. If they read properly, then problem is external to TSS.
29.	Pump discharge pressure meter on CTE panel reads zero during startup	29. (a) Improper patching (b) Signal not being generated in TSS (c) Bad interface	29. (a) Check analog patchboard; R20 to Q20. (b) Check Amp. 6147 for output. If no output, check flow simulation. (c) Read voltage output on Modulok 60-TB2-47D and 49-TB2-32D. If they read properly, then problem is external to TSS.

TSS System Failure Table - Engine System (cont.)

Item	Failure	Probable Cause		Corrective Action	
30.	Pump discharge temp. meter on CTE panel reads zero during startup	30. (a)	Improper patching	30. (a)	Check analog patchbaord; R22 to Q22.
		(b)	Signal not being generated in TSS	(b)	Check Amp. 6143 for output. If no output, check flow simulation.
		(c)	Bad interface	(c)	Read voltage output on Modulok 60-TB2-48D and 49-TB2-33D. If they read properly, then problem is external to TSS.
31.	PSOV meter on CTE panel reads zero during startup	31. (a)	Improper patching	31. (a)	Check analog patchboard; R19 to B47.
		(b)	Signal not being generated in TSS	(b)	Check Amp. 6132 for output. If no output, check flow simulation.
		(c)	Bad interface	(c)	Read voltage output on Modulok 60-TB1-101D and 49-TB2-34D. If they read properly, then problem is external to TSS.
32.	Chamber pressure meter on CTE panel reads zero during startup	32. (a)	Improper patching	32. (a)	Check analog patchboard; R23 to M24.
		(b)	Signal not being generated in TSS	(b)	Check Amp. 6145 for output. If no output, check flow simulation.
		(c)	Bad interface	(c)	Read voltage output on Modulok 60-TB2-62D and 49-TB2-35D. If they read properly, then problem is external to TSS.
33.	RSV 107 improper open position illumination at TSE console, SDS 19. LH ₂ control system	33. (a)	RSV 107 control signal shorted	33. (a)	Verify short does not exist at either Rack 67-TB10-013D or rack 60-TB1-049D. +28V is normal.
		(b)	K107 does not energize	(b)	Verify analog patchboard points FF45 to GG45 and FF46 to GG46 are connected.
		(c)	K107 coil open or shorted	(c)	Remove patching stated in step 1B and make continuity check between FF45 and FF46 to determine if a short or open exists.
		(d)	L107, A6153, no output	(d)	Verify K107 is energized and no external shorts to input or output of the ampl exist.
		(e)	Defective bulb or switch	(e)	Replace amplifier. Normal output is +10V.
		(f)	A6151 and A6150, 10% & 90% indicator amps, no output		Refer to system OI, ATP-001. Replace bulb or switch.
		(g)	K44 and K43, contact malfunction		
		(h)	K44 and K43, open coil		
		(i)	Defective cabling from rack 60 to 67.		

TSS System Failure Table - Engine System (cont.)

Item	Failure	Probable Cause	Corrective Action
33. (cont.)			<p>33. (f) Verify no external shorts to input and output of amplifier exist. Normal output is 11 volts. Replace amplifier.</p> <p>(g) Verify analog patchboard points FF47 to GG47 are patched. Remove patch from FF47 to GG47. Monitor FF47. 28 volts should be read when 10% point is exceeded. Remove patch from FF48 to GG48, monitor FF48. 28 volts should be read prior to 90% opening.</p> <p>(h) Remove relay network can and verify coil is open. Replace relay.</p> <p>(i) Verify no shorts or open exists at either rack 60-TB1-049B or Rack 67-TB10-013B.</p>
34.	RSV 107 improper closed position illumination at TSE console, SDS 19. LH ₂ control system	<p>34. (a) Defective cabling from rack 60 to rack 67</p> <p>(b) False RSV 107 control signal.</p> <p>(c) K44 and K43 contact failure</p>	<p>34. (a) Verify no shorts or open exists at either rack 60-TB1-049A or Rack 67-TB10-013A.</p> <p>(b) Verify zero volts exist at 60-TB1-049D.</p> <p>(c) Remove patching FF48 to GG48 and FF47 to GG47. FF48 should be 28 volts and FF47 should be zero.</p>
35.	RSV 201 improper open position illumination at TSE console, SDS 12. GH ₂ control system	<p>35. (a) RSV 201 control signal shorted</p> <p>(b) K201 does not energize</p> <p>(c) K201 coil open or shorted</p> <p>(d) L201, A5932, no output</p> <p>(e) Defective bulb or switch</p> <p>(f) A5936 and A5934, 10% & 90% indicator amps, no output</p> <p>(g) K52 and K51, contact malfunction</p>	<p>35. (a) Verify short does not exist at either Rack 67-TB10-015D or Rack 60-TB1-051D. +28V is normal.</p> <p>(b) Verify analog patchboard points DD45 to EE45 and DD46 to EE46 are connected.</p> <p>(c) Remove patching stated in Step 1B and make continuity check between DD46 and DD45 to determine if a short or open exists.</p> <p>(d) Verify K201 is energized and no external shorts to input or output of the amplifier exist. Replace amplifier. Normal output is +10V.</p>

TSS System Failure Table - Engine System (cont.)

Item	Failure	Probable Cause	Corrective Action
35. (cont.)		35. (h) K52 and K51, open coil. (i) Defective cabling from Rack 60 to Rack 67	35. (e) Refer to system OI, ATP-001. Replace bulb or switch. (f) Verify no external shorts to input and output of amplifier exist. Normal output is 11 volts. Replace amplifier. (g) Verify analog patchboard points DD47 to EE47 are patched. Remove patch from DD47 to EE47. Monitor DD47. 28 volts should be read when 10% point is exceeded. Remove patch from DD48 to EE48 monitor DD48. 28 volts should be read prior to 90% opening. (h) Remove relay network can and verify coil is open. Replace relay. (i) Verify no shorts or open exists at either Rack 67-TB10-015B or Rack 60-TB1-051B.
36.	RSV 201 improper closed position illumination at TSE console, SDS 12. GH ₂ control system.	36. (a) Defective cabling from Rack 60 to Rack 67 (b) False RSV 201 control signal. (c) K52 and K51 contact failure.	36. (a) Verify no shorts or open exists at either Rack 60-TB1-051A or Rack 67-TB10-015A. (b) Verify zero volts exists at 60-TB1-051D. (c) Remove patching EE48 to DD48 and DD47 to EE47. DD48 should be 28 volts and DD47 should be zero.
37.	RSV 460 improper open position illumination at TSE console, SDS 7. Cooldown control system.	37. (a) RSV 460 control signal shorted (b) K460 does not energize (c) K460 coil open or shorted (d) L460, A5861, no output (e) Defective bulb or switch (f) A5865 and A5864, 10% and 90% indicator amps, no output (g) K58 and K57, contact malfunction (h) K58 and K57, open coil (i) Defective cabling from Rack 60 to Rack 67	37. (a) Verify short does not exist at either Rack 67-TB10-009D or Rack 60-TB1-0450. +28V is normal. (b) Verify analog patchboard points W45 to V45 and W46 to V46 are connected. (c) Remove patching stated in Step 1B and make continuity check between V45 and V46 to determine if a short or open exists. (d) Verify K460 is energized and no external shorts to input or output of the ampl exist. Replace amplifier. Normal output is +10V. (e) Refer to system OI, ATP-001. Replace bulb or switch.

TSS System Failure Table - Engine System (cont.)

Item	Failure	Probable Cause	Corrective Action
37. (cont.)			<p>37. (f) Verify no external shorts to input and output of amplifier exist. Normal output is 11 volts. Replace amplifier.</p> <p>(g) Verify analog patchboard points W47 to V47 are patched. Remove patch from V47 to W47. Monitor V47. 28 volts should be read when 10% point is exceeded. Remove patch from V48 to W48. Monitor V47. 28 volts should be read prior to 90% opening.</p> <p>(h) Remove relay network can and verify coil is open. Replace relay.</p> <p>(i) Verify no shorts or open exist at either Rack 60-TB1-045B or Rack 67-TB10-009B.</p>
38.	RSV 460 improper closed position illumination at TSE console, SDS 7. Cooldown control system.	<p>38. (a) Defective cabling from Rack 60 to Rack 67</p> <p>(b) False RSV 460 control signal</p> <p>(c) K58 and K57 contact failure</p>	<p>38. (a) Verify no shorts or open exists at either Rack 60-TB1-045A or Rack 67-TB10-009A.</p> <p>(b) Verify zero volts exist at 60-TB1-009D.</p> <p>(c) Remove patching V48 to W48 and V47 to W47. V48 should be 28 volts and V47 should be zero.</p>
39.	RSV 454 improper open position illumination at TSE console, SDS 5. Cooldown control system.	<p>39. (a) RSV 454 control signal shorted</p> <p>(b) K454 does not energize</p> <p>(c) K454 coil open or shorted</p> <p>(d) L454, A5860, no output</p> <p>(e) Defective bulb or switch</p> <p>(f) A5863 and A5862, 10% & 90% indicator amps, no output</p> <p>(g) K56 and K55, contact malfunction</p> <p>(h) K56 and K55, open coil</p> <p>(i) Defective cabling from Rack 60 to Rack 67</p>	<p>39. (a) Verify short does not exist at either Rack 67-TB10-011D or Rack 60-TB1-047D. +28V is normal.</p> <p>(b) Verify analog patchboard points CC45 to BB45 and CC46 to BB46 are connected.</p> <p>(c) Remove patching stated in step (b) and make continuity check between BB45 and BB46 to determine if a short or open exists.</p> <p>(d) Verify K454 is energized and no external shorts to input or output of the ampl exist. Replace amplifier. Normal output is +10V.</p> <p>(e) Refer to system OI, ATP-001. Replace bulb or switch.</p> <p>(f) Verify no external shorts to input and output of amplifier exist. Normal output is 11 volts. Replace amplifier.</p>

TSS System Failure Table - Engine System (cont.)

Item	Failure	Probable Cause	Corrective Action
39. (cont.)			<p>39. (g) Verify analog patchboard points CC47 to BB47 are patched. Remove patch from BB47 to CC47. Monitor BB47. 28 volts should be read when 10% point is exceeded. Remove patch from BB48 to CC 48. Monitor BB48. 28 volts should be read prior to 90% opening.</p> <p>(h) Remove relay network can and verify coil is open. Replace relay.</p> <p>(i) Verify no shorts or open exist at either Rack 60-TB1-047B or Rack 67-TB10-011B.</p>
40.	RSV 454 improper closed position illumination at TSE console, SDS 5 cooldown control system	<p>40. (a) Defective cabling from Rack 60 to Rack 67</p> <p>(b) False RSV 454 control signal</p> <p>(c) K56 and K55 contact failure</p>	<p>40. (a) Verify no shorts or open exist at either Rack 60-TB1-047A or Rack 67-TB10-011A.</p> <p>(b) Verify zero volts exist at 60-TB1-047D.</p> <p>(c) Remove patching CC45 to BB45 and CC46 to BB46. BB45 should be 28 volts and BB46 should be zero.</p>
41.	RSV 78 improper open position illumination at TSE console, SDS 11, GHe control system	<p>41. (a) RSV 78 control signal shorted</p> <p>(b) K78 does not energize</p> <p>(c) K78 coil open or shorted</p> <p>(d) L78, A6005, no output</p> <p>(e) Defective bulb or switch</p> <p>(f) A6002 and A6004, 10% and 90% indicator amps, no output</p> <p>(g) K54 and K53, contact malfunction</p> <p>(h) K54 and K53, open coil</p> <p>(i) Defective cabling from Rack 60 to Rack 67</p>	<p>41. (a) Verify short does not exist at either Rack 67-TB10-003D or Rack 60-TB1-039D. +28V is normal.</p> <p>(b) Verify analog patchboard points JJ45 to HH25 and JJ46 to HH26 are connected.</p> <p>(c) Remove patching stated in step (b) and make continuity check between HH25 and HH26 to determine if a short or open exists.</p> <p>(d) Verify K78 is energized and no external shorts to input or output of the amplifier exist. Replace amplifier. Normal output is +10V.</p> <p>(e) Refer to system OI, ATP-001. Replace bulb or switch.</p> <p>(f) Verify no external shorts or input and output of amplifier exist. Normal output is 11 volts. Replace amplifier.</p> <p>(g) Verify analog patchboard points JJ47 to HH47 are patched. Remove patch from JJ47 to HH47. Monitor HH47. 28 volts should be read when 10% point is exceeded. Remove patch from JJ48 to HH48. Monitor HH48. 28 volts should be read prior to 90% opening.</p>

TSS System Failure Table - Engine System (cont.)

Item	Failure	Probable Cause	Corrective Action
41. (cont.)			41. (h) Remove relay network can and verify coil is open. Replace relay. (i) Verify no shorts or open exist at either Rack 60-TB1-039B or Rack-TB10-003B.
42.	RSV 78 improper closed position illumination at TSE console, SDS 11, GHe control system.	42. (a) Defective cabling from Rack 60 to Rack 67 (b) False RSV 78 control signal (c) K54 and K53 contact failure	42. (a) Verify no shorts or open exists at either Rack 60-TB1-039A or Rack 60-TB10-003A. (b) Verify zero volts exist at Rack 60-TB1-039D. (c) Remove patching JJ48 to HH48 and JJ47 to HH47. HH48 should be 28 volts and HH47 should be zero.
43.	RSV 545 improper open position at TSE console, SD8. LN ₂ control system.	43. (a) RSV 545 control signal shorted (b) K545 does not energize (c) K545 coil open or shorted (d) L545, A5973, no output (e) Defective bulb or switch (f) A5970 and A5972, 10% and 90% indicator amps, no output (g) K50 and K49, contact malfunction (h) K50 and K49, open coil (i) Defective cabling from Rack 60 to Rack 67	43. (a) Verify short does not exist at either Rack 67-TB10-001D or Rack 60-TB1-037D. +28V is normal. (b) Verify analog patchboard points U45 to T45 and U46 to T46 are connected. (c) Remove patching stated in Step (b) and make continuity check between T45 and T46 to determine if a short or open exists. (d) Verify K545 is energized and no external shorts to input or output of the amplifier exist. Replace amplifier. Normal output is +10V. (e) Refer to system OI, ATP-001. Replace bulb or switch. (f) Verify no external shorts to input and output of amplifier exist. Normal output is 11 volts. Replace amplifier. (g) Verify analog patchboard points U47 to T47 are patched. Remove patch from U47 to T47. Monitor T47. 28 volts should be read when 10% point is exceeded. Remove patch from U48 to T48. Monitor T48. 28 volts should be read prior to 90% opening. (h) Remove relay network can and verify coil is open. Replace relay. (i) Verify no shorts or open exist at either Rack 67-TB10-001B or Rack 60-TB1-037B.

TSS System Failure Table - Engine System (cont.)

Item	Failure	Probable Cause	Corrective Action
44.	RSV 545 improper closed position illumination at TSE console, SD8. LN ₂ control system	44. (a) Defective cabling from Rack 60 to Rack 67 (b) False RSV 545 control signal (c) K49 and K50 contact failure	44. (a) Verify no shorts or open exist at either Rack 67-TB10-001A or Rack 60-TB1-037A. (b) Verify zero volts exist at Rack 60-TB1-037D. (c) Remove patching U47 to T47 and U48 to T48. T48 should be 28 volts and T47 should be zero. If not refer to OI for ASE.
45.	PCV 251 no valve response	45. (a) Improper analog patching or grounding of demand signal (b) Defective cabling between TSS Rack 60 and Rack 67 (c) Amplifier Malfunction	45. (a) Verify analog patchboard points T20 to HH21 are connected. Unpatch and determine if short exists. (b) Verify no shorts or open exist at either Rack 67-TB8-022D or Rack 60-TB2-026D. (c) Refer to system OI for TSS.
46.	PSV 251 position, no indication, meter TSE-M5, cooldown control system	46. (a) No output, short or open, A5981 (b) Defective cabling between Rack 60 and Rack 67 (c) Amplifier Malfunction	46. (a) Verify analog patchboard points V21 to U21 and T21 to HH25 are connected. Unpatch V21 to U21 and determine if output is available at V21. (b) Verify no shorts or open exist at either Rack 60-TB2-026C or Rack 67-TB8-022C. (c) Refer to system OI for TSS.
47.	PCV 251 mult. input, No response. NOTE: Only when real actuator is used.	47. (a) Improper analog patching (b) Defective cabling between TSS Rack 60 to Rack 67	47. (a) Verify analog patchboard points T21 to HH25 are connected. (b) Verify no shorts or open exist at either Rack 60-TB2-026B or Rack 67-TB8-022B.
48.	PSV 517 no valve response	48. (a) Improper analog patching or grounding of demand signal (b) Defective cabling between TSS Rack 60 and Rack 67 (c) Amplifier Malfunction	48. (a) Verify analog patchboard points T16 to HH41 are connected. Unpatch and determine if short exists. (b) Verify no shorts or open exist at either Rack 67-TB8-018D or Rack 60-TB2-022D. (c) Refer to system OI for TSS.

TSS System Failure Table - Engine System (cont.)

Item	Failure	Probable Cause		Corrective Action	
49.	PCV 517 position, no indication, meter TSE - M10, LN ₂ control system	49. (a)	No output, short or open, A6189.	49. (a)	Verify analog patchboard points V41 to U16 and T17 to HH37 are connected. Unpatch V41 to U16 and determine if output is available at V41.
		(b)	Defective cabling between Rack 60 and Rack 67	(b)	Verify no shorts or open exist at either Rack 60-TB2-022C or Rack 67-TB8-018C.
		(c)	Amplifier malfunction	(c)	Refer to system OI for TSS.
50.	PCV 517 Mult. Input, no response. NOTE: Only when real actuator is used.	50. (a)	Improper analog patching	50. (a)	Verify analog patchboard points T17 to H37 are connected.
		(b)	Defective cabling between TSS Rack 60 to Rack 67.	(b)	Verify no shorts or open exist at either Rack 60-TB2-022B or Rack 67-TB8-018B.
51.	PCV 471 no valve response.	51. (a)	Improper analog patching or grounding of demand signal	51. (a)	Verify analog patchboard points T18 to HH40 are connected. Unpatch and determine if short exists.
		(b)	Defective cabling between TSS Rack 60 and Rack 67	(b)	Verify no shorts or open exist at either Rack 67-TB8-019D or Rack 60-TB2-023D.
		(c)	Amplifier Malfunction	(c)	Refer to system OI for TSS.
52.	PCV 471 position, no indication, meter TSE-M18. GHe control system.	52. (a)	No output, short or open, A6185.	52. (a)	Verify analog patchboard points V40 to U19 and T19 to HH23 are connected. Unpatch V40 to U19 and determine if output is available at V40.
		(b)	Defective cabling between Rack 60 and Rack 67	(b)	Verify no shorts or open exists at either Rack 60-TB2-023C or Rack 67-TB8-019C.
		(c)	Amplifier malfunction	(c)	Refer to system OI for TSS.
53.	PCV 471 Mult. Input, No response. NOTE: Only when real actuator is used.	53. (a)	Improper analog patching	53. (a)	Verify analog patchboard points T19 to HH23
		(b)	Defective cabling between TSS Rack 60 to Rack 67	(b)	Verify no shorts or open exist at either Rack 60-TB2-023B or Rack 67-TB8-019B.

TSS System Failure Table - Engine System (cont.)

Item	Failure	Probable Cause	Corrective Action
54.	PCV 472 no valve response	54. (a) Improper analog patching or grounding of demand signal. (b) Defective cabling between TSS Rack 60 and Rack 67. (c) Amplifier malfunction.	54. (a) Verify analog patchboard points T22 to H22 are connected. Unpatch and determine if short exists. (b) Verify no shorts or open exist at either Rack 67-TB8-021B or Rack 60-TB2-025D. (c) Refer to system OI for TSS.
55.	PCV 472 position, no indication, meter TSE-M10, LH ₂ control system	55. (a) No output, short or open, A5941. (b) Defective cabling between Rack 60 and Rack 67. (c) Amplifier malfunction	55. (a) Verify analog patchboard points U22 to V22 and H33 to T23 are connected. Unpatch V22 to U22 and determine if output is available at V22. (b) Verify no shorts or open exist at either Rack 60-TB2-025C or Rack 67-TB8-021C. (c) Refer to system OI for TSS.
56.	PCV 472 Mult. Input, No response. NOTE: Only when real actuator is used.	56. (a) Improper analog patching (b) Defective cabling between TSS Rack 60 to Rack 67.	56. (a) Verify analog patchboard points T23 to H33 are connected. (b) Verify no shorts or open exist at either Rack 60-TB2-025B or Rack 67-TB8-021B.
57.	CSV improper open position indication at console.	57. (a) CSV control signal shorted. (b) KCDSV does not energize (c) KCDSV coil open or shorted (d) CDSV, A5800, no output (e) Defective bulb or switch (f) Defective cabling from Rack 60 to Rack 63.	57. (a) Verify short does not exist at either Rack 63-TB2-082D or Rack 60-TB1-078D; +28V is normal. (b) Verify analog patchboard points S45 to R45 and S46 to R45 are connected. (c) Remove patching stated in step (b) and make continuity check between R45 and R46 to determine if a short or open exists. (d) Verify KCDSV is energized and no external shorts to input or output of the ampl exist. Replace amplifier. Normal output is +10 volts. (e) Refer to system OI, ATP-001. Replace bulb or switch. (f) Verify no shorts or open exist Rack 60-TB1-077D or Rack 63-TB2-083D.

TSS System Failure Table - Engine System (cont.)

Item	Failure	Probable Cause	Corrective Action
58.	RSV 459 improper open position illumination at TSE console, SDS 17. LH ₂ control system.	58. (a) RSV 459 control signal shorted. (b) K459 does not energize. (c) K459 coil open or shorted. (d) L459, A5951, no output. (e) Defective bulb or switch. (f) A5954 and A5955, 10% and 90% indicator amps, no output. (g) K48 and K47, contact malfunction. (h) K48 and K47, open coil. (i) Defective cabling from Rack 60 to Rack 67.	58. (a) Verify short does not exist at either Rack 67-TB10-007D or Rack 60TB1-043D. +28V is normal. (b) Verify analog patchboard points Y45 to X45 and Y46 to X46 are connected. (c) Remove patching stated in step (b) and make continuity check between X45 and X46 to determine if a short or open exists. (d) Verify K459 is energized and no external shorts to input or output of the ampl. exists. Replace amplifier. Normal output is +10V. (e) Refer to system OI, ATP-001. Replace bulb or switch. (f) Verify no external shorts to input and output of amplifier exist. Normal output is 11 volts. Replace amplifiers. (g) Verify analog patchboard points X47 to Y47 are patched. Remove patch from X47 to Y47. Monitor X47. 28 volts should be read when 10% point is exceeded. Remove patch from X48 to Y48. Monitor X48. 28 volts should be read prior to 90% opening. (h) Remove relay network can and verify coil is open. Replace relay. (i) Verify no shorts or open exist at either Rack 60-TB1-043B or Rack 67-TB10-007B.
59.	RSV 459 improper closed position illumination at TSE console, SDS 17. LH ₂ control system.	59. (a) Defective cabling from Rack 60 to Rack 67. (b) False RSV 459 control signal. (c) K48 and K47 contact failure.	59. (a) Verify no shorts or open exist at either Rack 60-TB1-043A or Rack 67-TB10-007A. (b) Verify zero volts exist at 60-TB1-043D. (c) Remove patching X47 to Y47 and X48 to Y48. X48 should be 28 volts and X47 should be zero.

TSS System Failure Table - Engine System (cont.)

Item	Failure	Probable Cause	Corrective Action
60.	RSV 458 improper open position illumination at TSE console, SDS 18. LH ₂ control system.	60. (a) RSV 458 control signal shorted. (b) K458 does not energize. (c) K458 coil open or shorted. (d) L458, A5950, no output. (e) Defective bulb or switch. (f) A5952 and A5953, 10% and 90% indicator amps, no output. (g) K46 and K45, contact malfunction. (h) K46 and K45, open coil. (i) Defective cabling from Rack 60 to Rack 67.	60. (a) Verify short does not exist at either Rack 67-TB10-005D or Rack 60-TB1-041D. +28V is normal. (b) Verify analog patchboard points AA45 to Z45 and AA46 to Z46 are connected. (c) Remove patching stated in Step (b) and make continuity check between Z45 and Z46 to determine if a short or open exists. (d) Verify K458 is energized and no external shorts to input or output of the amp exist. Replace amplifier. Normal output is +10V. (e) Refer to system OI, ATP-001. Replace bulb or switch. (f) Verify no external shorts to input and output of amplifier exist. Normal output is 11 volts. Replace amplifier. (g) Verify analog patchboard points Z47 to AA47 are patched. Remove patch from Z47 to AA47. Monitor Z47. 28 volts should be read when 10% point is exceeded. Remove patch from Z48 to AA48. Monitor Z48. 28 volts should be read prior to 90% opening. (h) Remove relay network can and verify coil is open. Replace relay. (i) Verify no shorts or open exist at either Rack 60-TB1-041B or Rack 67-TB10-005B.
61.	RSV 458 improper closed position illumination at TSE console, SDS 18. LH ₂ control system.	61. (a) Defective cabling from Rack 60 to Rack 67. (b) False RSV 458 control signal. (c) K46 and K45 contact failure.	61. (a) Verify no shorts or open exist at either Rack 60-TB1-041A or Rack 67-TB10-005A. (b) Verify zero volts exist at 60-TB1-041D. (c) Remove patching Z48 to AA48 and Z47 to AA47. Z48 should be 28 volts and Z47 should be zero.

TSS System Failure Table - Engine System (cont.)

Item	Failure	Probable Cause	Corrective Action
62.	TT474, TSE-M16 meter, fails to indicate. Cooldown control system.	62. (a) Improper analog patching (b) Defective cabling between Rack 60 and Rack 67. (c) Defective amplifier A5815.	62. (a) Verify analog patchboard points V5 to U5 are connected. (b) Verify no shorts or open exists at either Rack 60-TB2-007D or Rack 67-TB8-003D. (c) Refer to system OI for TSS. Verify no external short exists. Replace amplifier. Normal signal level is 0 to 5 volts.
63.	PT473, TSE-M16 meter, fails to indicate cooldown control system.	63. (a) Improper analog patching (b) Defective cabling between Rack 60 and Rack 67. (c) Defective amplifier A5830.	63. (a) Verify analog patchboard points 28 to U10 are connected. (b) Verify no shorts or open exist at either Rack 60-TB2-013D or Rack 67-TB8-009D. Refer to system OI for TSS. (c) Verify no external short exists. Replace amplifier. Normal signal level is 0 to 5 volts.
64.	PT484, TSE-M12 meter, fails to indicate. LH ₂ control system.	64. (a) Improper analog patching. (b) Defective cabling between Rack 60 and Rack 67. (c) Defective amplifier A5963.	64. (a) Verify analog patchboard points V17 to U17 are connected. (b) Verify no shorts or open exist at either Rack 60-TB2-017D or Rack 67-TB8-013D. (c) Refer to system OI for TSS. Verify no external short exists. Replace amplifier. Normal signal level is 0 to 5 volts, W17 signal is 3.24 volts at 1000 psia.
65.	TT55, TSE-M12 meter, fails to indicate, LN ₂ control system.	65. (a) Improper analog patching. (b) Defective cabling between Rack 60 and Rack 67. (c) Defective amplifier A6183.	65. (a) Verify analog patchboard points V39 to U11 are connected. (b) Verify no shorts or open exist at either Rack 60-TB2-005D or Rack 67-TB8-001D. Refer to system OI for TSS. (c) Verify no external short exists. Replace amplifier. Normal signal level is 0 to 0.702 volts.

TSS System Failure Table - Engine System (cont.)

Item	Failure	Probable Cause		Corrective Action	
66.	PT194, TSE-M11 meter, fails to indicate, LN ₂ control system.	66. (a)	Improper analog patching.	66. (a)	Verify analog patchboard points V37 to U13 are connected.
		(b)	Defective cabling between Rack 60 and Rack 67.	(b)	Verify no shorts or open exist at either Rack 60-TB2-014D or Rack 67-TB8-010D.
		(c)	Defective amplifier A6179.	(c)	Verify no external short exists. Replace amplifier. Normal signal level is 0 to 5 volts, W37 output level 3.9 at 250 psia.
67.	FE52, TSE-M9 meter, fails to indicate, LN ₂ control system.	67. (a)	Improper analog patching.	67. (a)	Verify analog patchboard points AA11 to U12 are connected.
		(b)	Defective cabling between Rack 60 and Rack 67.	(b)	Verify no shorts or open exist at either Rack 60-TB2-021D or Rack 67-TB8-017D. Refer to system OI for TSS.
		(c)	Defective amplifier A5896.	(c)	Verify no external short exists. Replace amplifier. Normal signal level is 0 to 5 volts.
68.	TT495, TSE-M8 meter, fails to indicate LH ₂ control system.	68. (a)	Improper analog patching.	68. (a)	Verify analog patchboard points V18 to U18 are connected.
		(b)	Defective cabling between Rack 60 and Rack 67.	(b)	Verify no shorts or open exist at either Rack 60-TB2-009D or Rack 67-TB8-005D. Refer to system OI for TSS.
		(c)	Defective amplifier A6164.	(c)	Verify no external short exists. Replace amplifier. Normal signal level is 0 to 0.4 volts.
69.	PT101, TSE-M11 meter, fails to indicate	69. (a)	Improper analog patching.	69. (a)	Verify analog patchboard points V35 to U14 are connected.
		(b)	Defective cabling between Rack 60 and Rack 67.	(b)	Verify no shorts or open exist at either Rack 60-TB2-016D or Rack 67-TB8-012D. Refer to system OI for TSS.
		(c)	Defective amplifier A6160.	(c)	Verify no external short exists. Replace amplifier. Normal signal level is 0 to 5 volts. W35 signal level equals 3.24V at 1000 psia.

TSS System Failure Table - Engine System (cont.)

Item	Failure	Probable Cause	Corrective Action
70.	FT12, TSE-M14 meter, fails to indicate	70. (a) Improper analog patching. (b) Defective cabling between Rack 60 and Rack 67 (c) Defective amplifier A6168.	70. (a) Verify analog patchboard points V33 to U3 are connected. (b) Verify no shorts or open exist at either Rack 60-TB2-018D or Rack 67-TB8-014D. Refer to system OI for TSS. (c) Verify no external short exists. Replace amplifier. Normal signal level is 0 to 10 volts.
71.	PT103, TSE-M18 meter, fails to indicate. Cooldown control system.	71. (a) Improper analog patching. (b) Defective cabling between Rack 60 and Rack 67. (c) Defective amplifier A5831	71. (a) Verify analog patchboard points V7 to U7 are connected. (b) Verify no shorts or open exist at either Rack 60-TB2-015D or Rack 67-TB8-011D. (c) Refer to system OI for TSS. Verify no external short exists. Replace amplifier. Normal signal level is 0 to 5 volts 5V = 2500 psia.
72.	TT496, TSE-M4 meter, fails to indicate. Cooldown control system.	72. (a) Improper analog patching. (b) Defective cabling between Rack 60 and Rack 67 (c) Defective amplifier A5815.	72. (a) Verify analog patchboard points X6 to U6 are connected. (b) Verify no shorts or open exist at either Rack 60-TB2-006D or Rack 67-TB8-002D. Refer to system OI for TSS. (c) Verify no external short exists. Replace amplifier. Normal signal level is 0 to 6 volts.
73.	PT891, TSE-19 meter, fails to indicate. Cooldown control system.	73. (a) Improper analog patching. (b) Defective cabling between Rack 60 and Rack 67. (c) Defective amplifier A5833.	73. (a) Verify analog patchboard points V8 to U8 are connected. (b) Verify no shorts or open exist at either Rack 60-TB2-028D or Rack 67-TB8-032D. (c) Refer to system OI for TSS. Verify no external short exists. Replace amplifier. Normal signal is 0 to 5 volts. 5V = 2500 psia.

TSS System Failure Table - Engine System (cont.)

Item	Failure	Probable Cause	Corrective Action
74.	TT28, TSE-M5 meter, fails to indicate LH ₂ control system.	74. (a) Improper analog patching. (b) Defective cabling between Rack 60 and Rack 67. (c) Defective amplifier A6164	74. (a) Verify analog patchboard points V34 to U15 are connected. (b) Verify no shorts or open exist at either Rack 60-TB2-008D or Rack 67-TB8-004D. Refer to System OI for TSS. Verify no external short exists. (c) Replace amplifier. Normal signal level is 0 to 3.7 volts. W/8 signal level is 5 volts equals 610°R.
75.	FT15, TSE-M6 meter, fails to indicate. Cooldown control system	75. (a) Improper analog patching. (b) Defective cabling between Rack 60 and Rack 67. (c) Defective amplifier A5926	75. (a) Verify analog patchboard points V28 to U24 are connected. (b) Verify no shorts or open exist at either Rack 60-TB2-018D or Rack 67-TB8-014D. Refer to system OI for TSS. (c) Verify no external short exists. Replace amplifier. Normal signal level is 0 to 5 volts.
76.	PT475, TSE-M20 meter, fails to indicate. Cooldown control system.	76. (a) Improper analog patching. (b) Defective cabling between Rack 60 and Rack 67. (c) Defective amplifier A5894	76. (a) Verify analog patchboard points Z6 to U2 are connected. (b) Verify no shorts or open exists at either Rack 60-TB2-012D or Rack 67-TB8-008D. Refer to system OI for TSS. (c) Verify no external short exists. Replace amplifier. Normal signal level is 0 to 5 volts. 5V = 2500 psia.
77.	FT415, TSE-M15 meter, fails to indicate GHe control system	77. (a) Improper analog patching. (b) Defective cabling between Rack 60 and Rack 67 (c) Defective amplifier A5902	77. (a) Verify analog patchboard points V23 to U23 are connected. (b) Verify no shorts or open exist at either Rack 60-TB2-020D or Rack 67-TB8-016D. Refer to system OI for TSS. (c) Verify no external short exists. Replace amplifier. Normal signal level is 0 to 5 volts.

TSS System Failure Table - Engine System (cont.)

Item	Failure	Probable Cause	Corrective Action
78.	TT45, TSE-M13 meter, fails to indicate GHe control system.	78. (a) Improper analog patching. (b) Defective cabling between Rack 60 and Rack 67 (c) Defective amplifier A5828	78. (a) Verify analog patchboard points V31 to U20 are connected. (b) Verify no shorts or open exist at either Rack 60-TB2-010D or Rack 67-TB8-006D. Refer to system OI for tests. (c) Verify no external short exists. Replace amplifier. Normal signal level is 0 to 5 volts. 5V = 560°R
79.	TT881, TSE-M17 meter, fails to indicate	79. (a) Improper analog patching. (b) Defective cabling between Rack 60 and Rack 67. (c) Defective amplifier A5815	79. (a) Verify analog patchboard points W9 to U5 and V9 to U4 are connected. (b) Verify no shorts or open exist at either Rack 60-TB2-027D or Rack 67-TB8-033D. Refer to system OI for TSS. (c) Verify no external short exists. Replace amplifier. Normal signal level is 0 to 5 volts.

TEST SIMULATION UNITS - RACKS 58-62

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1. DESCRIPTION AND PURPOSE

1.1 INTRODUCTION

This manual is intended to be a useful tool to help understand the operation, maintenance and the theory concerning the computer simulation of the engine and cooldown systems for ETS-1. Refer to Figure 1 for special symbols used to describe the circuit components.

1.2 GENERAL DESCRIPTION

The Test Simulation System (TSS) for ETS-1 is shown in Figures 2 and 3 and is housed in Racks 58, 59, 60, 61 and 62, within the Test Cell Building. This test simulation system is used for training of operating personnel and checkout of the facility and engine control systems. The equipment was built by Electronics Associated, Inc., of Long Branch, New Jersey.

The simulator is an electronic simulation of the mathematical equations which define the engine and cooldown system. The hardware is arranged so that the engine simulation and the cooldown simulation can function independently. The simulator consists of network cans plus standard analog computing modules. These cans and modules can easily be inserted or removed from their blue-ribbon connectors by sliding in and out from the front of the rack. Most maintenance and repair can be done by replacing commercial plug-in units or replacing components within the network cans on a work bench away from the close quarters of the simulator itself.

1.2.1 Functional Description

The simulator is a special purpose, ± 10 volt, partially hard-wired solid state analog-digital controlled computer. The simulation is subdivided into groups called functional groups. Each group is a hard-wired

COMPONENT	FUNCTION	COMPONENT	FUNCTION	COMPONENT	FUNCTION	COMPONENT	FUNCTION	COMPONENT	FUNCTION	COMPONENT	FUNCTION
CIRCLE IN SYMBOL IS OVERLOAD INDICATOR			$V = -X$		$V = X + Y + Z$		USED FOR INDICATING EXTRA INPUT RESISTORS OR SPECIAL INPUTS MADE DIRECTLY TO SJ (SUMMING JUNCTION) OR AMPLIFIER		INDICATES AN INPUT RESISTOR NETWORK DISCONNECTED FROM ITS ASSOCIATED AMPLIFIER (IN THIS CASE #18) AND USED WITH ANOTHER AMPLIFIER (IN THIS CASE #16)		$V = V_c$ $-\int^t (X + 10Y + Z) dt$
HIGH GAIN AMPLIFIER	$E_1 + 10E_2 + E_3 = 0$	INVERTER	SOME INVERTERS HAVE INPUT MULTIPLIERS OTHER THAN ONE (1)	SUMMER	THE NUMBER OF INPUTS AVAILABLE PER AMPLIFIER IS DEPENDENT UPON THE COMPUTER	AMPLIFIER WITH SUMMER JUNCTION INPUT		BORROWED INPUT RESISTOR NETWORK		INTEGRATOR	THE MODE CONTROL INPUT IS A LOGIC SIGNAL FOR CHANGING THE MODE OF THE INTEGRATOR. IF CONVENTIONAL MODE CONTROL IS USED, THIS INPUT MAY BE OMITTED

COMPONENT	FUNCTION	COMPONENT	FUNCTION	COMPONENT	FUNCTION	COMPONENT	FUNCTION	COMPONENT	FUNCTION	COMPONENT	FUNCTION	COMPONENT	FUNCTION
NO CHARACTER IN SYMBOL INDICATES KNOB ADJUST POTENTIOMETER			$V = KX$ $0 \leq K \leq +1$		$V = KX + (1-K)Y$ $0 \leq K \leq +1$		$V = \frac{XY}{10}$		$V = f(X)$		$V = f(X)$		$V = \frac{XY}{10}$
T = SCREW ADJUST TRIMPOT POTENTIOMETER (GROUNDING)		POTENTIOMETER (UNGROUNDING)		SERVO-MULTIPLIER (PLUS CONNECTION)	USE ONLY IF X IS ALWAYS POSITIVE	QUARTER-SQUARE MULTIPLIER (WITH EXTERNALLY PATCHED AMPLIFIER)	$V = \pm \frac{XY}{10}$	DIODE FUNCTION GENERATOR (WITH AMPLIFIERS INCLUDED)		DIODE FUNCTION GENERATOR (WITH EXTERNALLY PATCHED AMPLIFIERS)		QUARTER-SQUARE MULTIPLIER (WITH EXTERNALLY PATCHED AMPLIFIERS)	THE SIGN OF THE OUTPUT IS DETERMINED BY INPUT PATCHING

COMPONENT	FUNCTION	COMPONENT	FUNCTION	COMPONENT	FUNCTION	COMPONENT	FUNCTION	COMPONENT	FUNCTION	COMPONENT	FUNCTION	COMPONENT	FUNCTION
NUMBER OF LIMITS			VERY SLIGHT SLOPE (APPROX 1/10)		WHEN POINT A IS POSITIVE WITH RESPECT TO K, CURRENT FLOWS FROM A TO K. WHEN POINT A IS NEGATIVE WITH RESPECT TO K, NEGLIGIBLE CURRENT FLOWS. IT IS NOT NECESSARY TO INCLUDE THE LETTERS A AND K ON THE DIAGRAM		ALLOW MULTIPLE CONNECTIONS TO A SINGLE TERMINAL		RELAY ARMS MAKE TO "A" CONTACTS WHEN $X + Y > 0$ AND TO "B" CONTACTS WHEN $X + Y < 0$. COMPARATOR CONTACTS NEED NOT BE DRAWN ADJACENT TO THE CONTROL INPUTS X AND Y		$V = \pm \frac{XY}{10}$		THE SIGN OF THE OUTPUT IS DETERMINED BY INPUT PATCHING THE "X" QUANTITY INPUT CAN BE A (1) VALUE ONLY.
FEEDBACK LIMITER (SOFT LIMITER)	MAY BE USED WITH ANY TYPE OF AMPLIFIER (SUMMER, INTEGRATOR, ETC.)	SOLID-STATE DIODE		TIE POINT	INPUT OR OTHER COMPONENT	MANUAL SWITCH (FUNCTION SWITCH)		RELAY COMPARATOR		DIVISION CIRCUIT USING QUARTER-SQUARE MULTIPLIER (WITH EXTERNALLY PATCHED AMPLIFIER)		DIVISION CIRCUIT USING QUARTER-SQUARE MULTIPLIER (WITH EXTERNALLY PATCHED AMPLIFIERS) DENOMINATOR Y CAN BE SHOWN ENTERING TOP OR BOTTOM	SAME AS ABOVE

COMPONENT	FUNCTION	COMPONENT	FUNCTION	COMPONENT	FUNCTION
	$V = -\sqrt{10X}$		$V = -\frac{X^2}{10}$		PERMITS INTERCONNECTION BETWEEN CONSOLES
SQUARE ROOT CIRCUIT USING FIXED DIODE FUNCTION GENERATOR & HIGH GAIN AMP	WHERE INPUT X IS (4) SQUARE CARD IS USED IN FEEDBACK TO GIVE SQUARE ROOT OUTPUT	SQUARE CIRCUIT USING FIXED DIODE FUNCTION GENERATOR & HIGH GAIN AMPLIFIER	OUTPUT IS SQUARED & DIVIDED BY 10	INTERCONSOLE CONNECTION TRUNK	
	SAME AS ABOVE		SAME AS ABOVE		
SQUARE ROOT Ckt. USING FIXED DIODE FUNCTION GENERATOR (WITH INTERNALLY PATCHED AMPLIFIER)		SQUARE Ckt. USING FIXED DIODE FUNCTION GENERATOR (WITH INTERNALLY PATCHED AMPLIFIER)			

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DATE 10/10

Figure 1 - Special Symbols

Figure 2 - Test Stand Simulator for ETS-1: Front View

Figure 3 - Test Stand Simulator for ETS-1: Rear View

package and identified as a specific functional group. Inputs and outputs to the functional groups are such that they are programmable from a patchboard. Individual computing elements do not have patchboard programming capability.

The test stand simulator can logically be separated into five hardware sections: (1) Engine Simulation, (2) Cooldown Simulation, (3) Digital Logic, (4) Analog Patchbay, and (5) Digital Voltmeter.

The Engine Simulation (AGC Drawing 1114313) is composed of eleven functional groups packaged in three, five-shelf housings (Racks 61A, 62A and 62B), while the cooldown simulation (AGC Drawing 1114289) is made up of eleven functional groups with fourteen subgroups sharing some common components, thus making it the equivalent of nineteen separate groups. The cooldown simulation is packaged in five, five-shelf and one, three-shelf housings (Racks 58A, 58B, 59A, 59B, 61B and 60A).

The inputs and outputs of the simulator will be within the boundaries of ± 10 volts. The inputs come from the Engine Control System, Process System, other parts of the TSS, or it may come from actual hardware such as PCV valves. Outputs can go to the Engine Control System, Process System, other parts of the TSS, actual hardware and to display meters located on the control consoles. All inputs and outputs to the simulator terminate on either TB1 or TB2 in the rear of Rack 60.

Each housing, one-half of a rack, has a separate DC power supply together with a ± 10 volt reference regulator. All external connections to each housing are terminated on four separate modulok terminal strips (TB1, TB2, TB3 and TB4) located directly in the rear of the racks. These strips are the terminations where all patchboard connections are made from and into the individual housing. This information is better illustrated in Figures 4 and 5.

Figure 4 - Hardware Sectional Make-Up of TSS: Front View

Figure 5 - Hardware Sectional Make-Up of TSS: Rear View

1.2.2 Physical Description

The Test Simulation System is housed in five relay racks. These racks are identified with rack numbers 58, 59, 60, 61 and 62. Refer to AGC Drawing 1114573 and the following figures for a hardware description:

Figure 2, Test Stand Simulator for ETS-1: Front View

Figure 3, Test Stand Simulator for ETS-1: Rear View

Figure 4, Hardware Sectional Makeup of TSS: Front View

Figure 5, Hardware Sectional Makeup of TSS: Rear View

1.3 INTERFACE

1.3.1 Unit

All plug-in units terminate into connectors at the rear of each racks housing.

1.3.2 Signal

Signals entering and leaving the TSS are normally in the region of 0 to ± 10 volts since these are the limitations on the simulator. These signals terminate in moduloks at the rear of Rack 60.

1.3.3 Power

28 VDC Control Point Building power from Rack 01L.

28 VDC Test Cell Building direct.

115 VAC Test Cell Building direct.

1.3.4 Physical

Overall dimensions of the TSS are 77.12 inches high, 120 inches wide by 28 inches deep. The TSS weighs approximately 2,000 pounds.

1.4 APPLICABLE DOCUMENTS

1.4.1 Drawings

Refer to Table 1 for a list of applicable drawings.

1.4.2 Specifications

- (a) NDC-118
- (b) AGC-90073 - Equipment Specification Test Simulation System (TSS)

1.4.3 Component Documents

See Table 2 for a list of commercial component manuals.

1.4.4 Cable Tab Sheets

Refer to the current ETS-1 Unit List for signal interface.

TABLE 1

RACKS 58 THROUGH 62 DRAWING CONFIGURATION

1114573 (AGC)	Rack Assy TSS-ETS-1, TSCS
1116114 (AGC)	Rack ETS-1, TSCS
1115260 (AGC)	Rack Assy - ETS-1, TSCS
1115261 (AGC)	TEE-ETS-1, TSCS
1115262 (AGC)	Channel, ETS-1, TSCS
1113973 (AGC)	Rack - ETS-1, TSCS
1113893 (AGC)	Rack Assy
0000101160A (EAI)	Assy TSS for Aerojet-General (PC-12)
0001214350S (EAI)	Schematic, Relay Network
04.00517 (EAI)	Schematic, Logic and Control Panel
0001214860S (EAI)	Schematic, Dual Boost
0207870S (EAI)	Schematic, Control Panel
04.00590 (EAI)	Cooldown Simulation Block Diagram for TSS
04.00591 (EAI)	Engine Simulation Block Diagram for TSS
0000101160S (EAI)	Schematic TSS Aerojet-General (PC-12)
44000X (EAI)	Wiring (Standard Bus)
0130410S (EAI)	Schematic Diagram Visual Ov'ld Indicator
44054XS (EAI)	Schematic Diagram, $\pm$ Limiter
1114548 (AGC)	Schematic, Linear Pwr Range Generator - ETS-1, TSCS
1114289 (AGC)	Computer Diagram, Cooldown Simulation
1114329 (AGC)	Flow Diagram, Cooldown Simulation - ETS-1, TSCS, Concept
1114313 (AGC)	Computer Diagram, Engine Simulation
1114315 (AGC)	LH ₂ Engine Flow Diagram, TSS ETS-1, TSCS Concept
0000402300A (EAI)	Assembly Rack 58
0001214350A (EAI)	Assembly, Relay Network
000121454 (EAI)	Network, 5800
000121455 (EAI)	Network, 5801
000121456 (EAI)	Network, 5802
000121457 (EAI)	Network, 5803
000121458 (EAI)	Network, 5804

0000101160A

TABLE 1 (cont.)

0000402300A

000121459 (EAI)	Network, 5805
000121460 (EAI)	Network, 5806
000121496 (EAI)	Network, 5807
000121453 (EAI)	Network, 5808
000121492 (EAI)	Network, 5809
000121493 (EAI)	Network, 5810
000121494 (EAI)	Network, 5811
000121495 (EAI)	Network, 5812
000121497 (EAI)	Network, 5813
39882XA (EAI)	Assembly Aerojet Rack
39878XA (EAI)	Assembly Door (Aerojet Rack)

0000402290A (EAI) Assembly Rack 59

0001214350A (EAI)	Assembly, Relay Network
000121447 (EAI)	Network, 5900
000121449 (EAI)	Network, 5901
000121450 (EAI)	Network, 5902
000121448 (EAI)	Network, 5903
000121437-2 (EAI)	Network, 5904
000121439-3 (EAI)	Network, 5905
000121482 (EAI)	Network, 5906
000121483 (EAI)	Network, 5907
000121484 (EAI)	Network, 5908
000121490 (EAI)	Network, 5910
000121491 (EAI)	Network, 5911
000121440 (EAI)	Network, 5912
000121439-2 (EAI)	Network, 5913
000121452 (EAI)	Network, 5914
000121500 (EAI)	Network, 5920
39882XA (EAI)	Assembly Aerojet Rack
39878XA (EAI)	Assembly Door (Aerojet Rack)
0001214860A (EAI)	Assembly Dual Boost

TABLE 1 (cont.)

0000101160A

0000402280A (EAI)	Assembly Rack 60
0001214350A (EAI)	Assembly, Relay Network
000121487 (EAI)	Network, 6000
000121488 (EAI)	Network, 6001
000121489 (EAI)	Network, 6002
39882XA (EAI)	Assembly Aerojet Rack
39878XA (EAI)	Assembly Door (Aerojet Rack)
04.00491 (EAI)	Bracket, Logic and Control Panel for TSS
04.00492 (EAI)	Rear Panel, Logic and Control Panel for TSS
04.00493 (EAI)	Front Panel, Logic and Control Panel for TSS
04.00494 (EAI)	Side Panel, Logic and Control Panel for TSS
04.00495 (EAI)	Mounting Bar, Logic and Control Panel for TSS
04.00496 (EAI)	Chassis Covers, Logic and Control Panel for TSS
04.00502 (EAI)	Silkscreen Information Analog Patchboard for TSS
04.00520 (EAI)	Component Layout, Logic and Control Panel for TSS
04.00521 (EAI)	Layout, Logic Patchboard for TSS
04.00523 (EAI)	Silkscreen Information Logic Patchboard for TSS
04.00524 (EAI)	Layout, Analog Patchboard for TSS
04.00533 (EAI)	Silkscreen Information Logic and Control Panel for TSS
04.00545 (EAI)	Mounting Frame, Analog Patchboard for TSS
04.00546 (EAI)	Mounting Frame, Logic Patchboard for TSS
04.00551 (EAI)	Logic Diagram, Logic and Control Panel for TSS
6000 (EAI)	Digital Voltmeter
0000402270A (EAI)	Assembly Rack 61
0001214350A (EAI)	Assembly, Relay Network
000121466 (EAI)	Network, 6100
000121468 (EAI)	Network, 6101
000121467 (EAI)	Network, 6102
000121471 (EAI)	Network, 6103
000121451 (EAI)	Network, 6104

0000101160A

TABLE 1 (cont.)

0000402270A

000121465 (EAI)	Network, 6105
000121472 (EAI)	Network, 6106
000121470 (EAI)	Network, 6107
000121442 (EAI)	Network, 6108
000121443 (EAI)	Network, 6109
000121444 (EAI)	Network, 6110
000121446 (EAI)	Network, 6111
000121445 (EAI)	Network, 6112
000121437-1 (EAI)	Network, 6113
000121439-1 (EAI)	Network, 6114
000121437 (EAI)	Network, 6115
000121439 (EAI)	Network, 6116
39882XA (EAI)	Assembly Aerojet Rack
39878XA (EAI)	Assembly Door (Aerojet Rack)
PA-6 (EGG)	Intercom Panel

0000402260A (EAI)	Assembly Rack 62
00012014860A (EAI)	Assembly Dual Boost
0001214350A (EAI)	Assembly, Relay Network
000121473-1 (EAI)	Network, 6200
000121474 (EAI)	Network, 6201
000121461 (EAI)	Network, 6202
000121477 (EAI)	Network, 6203
000121479 (EAI)	Network, 6204
000121478 (EAI)	Network, 6205
000121462 (EAI)	Network, 6206
000121480 (EAI)	Network, 6207
000121481 (EAI)	Network, 6208
000121475 (EAI)	Network, 6209
000121476 (EAI)	Network, 6210
000121463 (EAI)	Network, 6211

0000101160A

TABLE 1 (cont.)

0000402260A

000121464 (EAI)	Network, 6212
000121469 (EAI)	Network, 6213
000121473 (EAI)	Network, 6214
000121498 (EAI)	Network, 6215
39882XA (EAI)	Assembly Aerojet Rack
39878XA (EAI)	Assembly Door (Aerojet Rack)

TABLE 2

STANDARD MODULE MANUAL REFERENCES

<u>Item Number</u>	<u>Model Number</u>	<u>Description</u>	<u>Manual Title</u>	<u>Publication No.</u>
1.	6.368	Dual D.C. Amplifier	6.368 Dual D.C. Amplifier	EAI 00 800.6006-0
2.	13.029	Plug-In Overload Indicator	6.358 Dual D.C. Amplifier	EAI 00 800.6006-0
3.	12.1433-0	Dual Integrator	Dual Integrator Network Model 12.1433-()	EAI 00 802.6005-0
4.	16.282	Dual X^2	Dual X^2 Diode Function Generator Model 16.282	EAI Original Printing 7/16/62
5.	16.242	High Acc. Log DFG	Log X Diode Function Generators 16.242 & 16.243	EAI Original Printing 4/63
6.	16.342 & 16.343	VBP VDFG	Variable Diode Function Generators Models 16.342 & 16.343	EAI 00 802.6003-0
7.	7.881	QSM	Quarter Square Multiplier Model 7.081	EAI February 1964
8.	7.147	High Acc. QSM	Bi-Polar Multiplier Model 7.147	EAI 00 802.6004-0
9.	2.489	Set-up Box	PC-12 Set-up Panel and Assemblies, 48.020, 2.478, and 2.489	EAI June 1965
10.	10.165	Regulated Power Supply	Regulated Power Supply Model 10.165	EAI 00 800.6012-0
11.	43.101	Reference Regulator	Reference Regulator Model 43.101	EAI P 800.6016-OC
12.	26.257	DVM	6000 and 6001 Series Digital Voltmeters Models 26.257 and 26.203	EAI D800.5003-1I
13.	C-105	Inverter R107, Nand Gate R121, Solenoid Driver W040, & Flip-Flop R204	The Digital Logic Handbook	DEC 1966-67 Edition

2. INSTALLATION AND OPERATION

2.1 SAFETY PRECAUTIONS

Before installing or removing plug-in units, make sure the +30 VDC, +15 VDC and +10 VDC is "off" for that unit's rack.

2.2 INSTALLATION

The TSS shall be installed in the Test Cell Building in accordance with AGC Drawing 1115685. Input and output circuits are to be connected in accordance with AGC Drawing 1115951.

2.3 ADJUSTMENT AND CALIBRATION

See Sections 4.2 and 4.3.

2.4 OPERATION

2.4.1 General Setup Procedures

To minimize redundant efforts in the preparation of this manual, it was necessary to describe separately and generally each operational setup procedure which is common to more than one functional group and at the same time is peculiar to this special purpose analog computer.

2.4.1.1 Setting Limits

Basically, the technique in setting a limiter is to insert a voltage of opposite polarity to that of the limiter into the amplifier involved such that the potential on the output of the amplifier just exceeds

the desired limit value. Setting the limit in this manner assures that the static limit and the dynamic limit are the same.

2.4.1.2 DFG Setup Position

Positions Rack 61A, Row V, Slots 18 through 20 were used to provide a convenient setup fixture for all DFGs. Slots 18 and 19 are hard-wired for a dual amplifier with both amplifier outputs appearing on the patch-panel. Slot 20 is hard-wired for a +DFG connecting the adjacent amplifier inputs and with the +DFG input appearing on the patch panel. When the setup fixture is not being used, the amplifier and DFG extension card are removed and two blank panels inserted.

When in use, an extension card is inserted to allow ready access to the DFG's slope and break point adjustments as illustrated in Figure 6. For detailed setup procedures once the fixture is made ready, refer to the Variable Diode Function Generator Manual.

2.4.1.3 Potentiometer Gain Settings

All potentiometers (also can be referred to as attenuators) gain settings are obtained using the same fundamental setup procedure which is:

If a voltage e_i is applied to the top of a potentiometer whose other end is grounded, the voltage e_o at the unloaded wiper is:

$$e_o = k e_i$$

where k is the potentiometer gain setting ($0 \leq k \leq 1$).

Figure 6 - DFG Setup Fixture

Consequently, all gain settings of potentiometers which have their high side directly connected to a patch point or to a reference supply can be set in a straightforward manner. All other potentiometers within the various functional groups require the use of subtle techniques to place a constant voltage e_1 to the high side of a potentiometer. These techniques can be generalized and separated into three methods. However, it should be noted that efficient use of these approaches only comes with operating experience.

(a) Integrator Mode Control Method - Integrators, particularly those with I.C. potentiometers, provide ideal means of opening closed loops within functional groups and thus place constant voltages on the high side of all potentiometers contained within the same loops.

(b) Selection of Key Potentiometer Method - Quite often after a thorough review of functional group circuit is made, one can find a potentiometer which is the key to a method of opening a closed loop. This opening is accomplished by turning that particular potentiometer to zero, and thus allow the other potentiometers within the loop to be set. Detailed knowledge and understanding of the particular loop involved enables the gain of the key potentiometer to be set.

(c) "Brute Force" Method - This method requires that the particular network can be removed (power to the rack should be turned off prior to removal) to allow direct access for applying a constant voltage to the high side of the potentiometer. This method requires the use of the appropriate schematic, EAI 0101160, in order to identify the connection pin which is connected to the high side of a potentiometer and removing the module retaining bar.

Normally methods (a) and (b) or a combination of both is all that is necessary to set potentiometer gains within functional groups. However, there can be times when the use of the "brute force" method is required.

WARNING

A great deal of care must be taken when patching the analog patchboard while in place! The patch cord pin wiper design is such that they can be easily damaged by inserting patch cords while the patchboard is in place. A rule that should be followed while patching is to always disengage the analog patchboard first!

2.4.1.4 Logic Setup Procedures

Setup procedures for each functional group have been described in the corresponding section of this manual and will not be repeated here. To completely patch the logic to operate the TSS, the following steps are to be followed:

	Patch				Function
	Row		Columns		
	From	To	From	Through	
(1)	2	3	A	Z	Logic Inputs
(2)	5	6	A	Z	Logic Controls
(3)	15	16	A	E	Engine Compute
(4)	15	16	G	L	Engine I.C.
(5)	16	17	N	R	Engine Control Relays
(6)	18	19	A	C	Liquid Hydrogen Compute
(7)	18	19	G	J	Liquid Hydrogen I.C.
(8)	19	20	N	U	Liquid Hydrogen Control Relays
(9)	21	22	A	C	Liquid Nitrogen Compute
(10)	21	22	G	J	Liquid Nitrogen I.C.
(11)	22	23	N	T	Liquid Nitrogen Control Relays
(12)	24	25	A	D	Gaseous Hydrogen Compute
(13)	24	25	G	K	Gaseous Hydrogen I.C.
(14)	25	26	N	V	Gaseous Hydrogen Control Relays
(15)	27	28	A	E	Gaseous Helium Compute
(16)	27	28	G	L	Gaseous Helium I.C.
(17)	28	29	N	U	Gaseous Helium Control Relays
(18)	33	34	B	Y	Log-Linear Power Generators

2.4.1.5 RSV Setup Procedure

To set or change the RSV actuator simulator (one amplifier simulation of a second order system), the following procedure is recommended to obtain the desired transfer function:

- (a) Turn off rack power and remove the appropriate network can.
- (b) Refer to the EAI Drawing 00101160A to obtain pin connections associated with each variable resistor (potentiometer).
- (c) Set R1 and R6 to the desired values on AGC Drawings 1114289 and 1114313 using a precision bridge.
- (d) Reinsert the network can and turn on rack power and allow the amplifier to stabilize.
- (e) Monitoring the output of the amplifier, actuate the actuator simulation relay and then adjust R4 until the output is equal to +10.00 volts. (R4 must equal R1 for unity gain.)
- (f) Deactivate the actuator simulator relay and remove the can again turning off rack power; short-out (jumper) the overload protection diode (two eleven volt zeners) and then set the parallel resistance with a precision bridge corresponding to R5 and R4 in parallel by adjusting R5 (note $R4 = R1$).
- (g) Remove jumper, reinsert the network can, and turn on rack power.

2.4.2 Location Designation

Generally speaking, all modular components can be located with a housing number and letter, a shelf number and a position number. For example, take the + VDFG, Model No. 016.0343, located in position 62B-V-3. This means that this VDFG is located in Rack 62, B housing, on the fifth shelf in position 3. Therefore, the following position location generalization can be made:

WWX Y - Z

Where:

- WW Designates the rack number.
- X Designates the housing location. The letter A designates the first (or upper) housing and the letter B designates the second (or lower) housing.
- Y Designates, using the Roman numerals, the shelf location within a particular housing.
- Z Designates the shelf position location using numbers 1 through 20. Each number represents 3/4 inches.

Modulok terminal strips are located by rack, housing, number (strips are numbered from left to right facing the rear of the rack), and terminal location. A typical terminal identification example is illustrated as follows:

62A TB2 -3A

This terminal is located in the rear of the upper housing of Rack 62 on modulok terminal strip number 2 in position 3A. Note that there are four separate terminals A through D for each numerical terminal position on any particular strip. Therefore, the following position location generalization can be made:

WWX TB α - $\beta\gamma$

Where:

- WW and X are previously identified.
- TB Designates terminal.
- α Designates terminal number. Can be any number from 1 to 4.
- β Designates numerical terminal position starting from the top of a particular strip.
- γ Designates, using letters A through D, the particular terminal at a particular numerical terminal position.

When it is obvious which housing is being referenced, the rack and housing identification is dropped.

Supplemental position location identification numbers were also used to facilitate the drafting of wiring and operator schematics. Four-digit numbers were assigned to all amplifiers and special network modules in lieu of the above described method. The first two digits were used to identify the particular rack in which the module is located and the remaining two digits were used to maintain a sequential format. However, you may notice, from time to time, that this sequence becomes interrupted. This is due to design changes being incorporated following the hardware fabrication phases.

2.4.3 General Logic Information

The logic control portion of the TSS provides control and decision making capability for the analog portion of the machine. Input information in the form of logic voltage levels (ground, -3 v) is connected to the logic chassis from the logic patchboard. Preprogrammed logical decisions are performed on the information and commands in the form of relay driving voltages (ground or -22 v) are connected back to the patchboard for connection to relays located throughout the TSS.

Logic levels necessary to activate the logic input circuits are ground and -3 v. The input interface has been designed so that a ground at any input represents a "true" or logic high condition. A -3 v level has been incorporated into all logic input commands to represent a "false" or logic low level for ease of monitoring the status of the inputs with the DVM. Therefore, all logic inputs are either at a -3 v or ground level and can easily be monitored on row 1 of the logic patchboard.

The relays, which provide the initial condition, compute, fluid select on equipment shared functions, etc., have been connected so that a ground applied to the coil inputs located on the logic patchboard will activate the relay. Therefore, the logic output driving circuit applies a ground to its associated coil whenever the logic requires the relay to be activated.

The logic is completely transistorized and utilizes Digital Equipment Corporation "flip chip" Nand-Nor logic implementation. Transistor relay output drivers are each capable of driving 600 ma of inductive load or approximately 40 (net. 12.1435) relays (15 ma each) or 15 integrator (net. 12.1433) initial condition or compute relays (40 ma each).

All relay drivers have been protected with inductive surge suppression networks.

Twenty 5K attenuator potentiometers and ten function switches are also located on the control and logic front panel; their outputs are located on the analog patchboard.

2.4.3.1 Logic Location

The logic section is contained in the logic and control chassis located in the center of Rack 60. All controls are located on the front panel and include "Initial Condition, Compute, Hold, and Reset Control"

push-buttons in addition to a "Remote/Local" indicator light and a "Power On-Off" switch. The power OFF switch will remain lit when the unit is turned off to indicate the power chain has been completed to the TSS.

2.4.3.2 Operational Mode

The logic output driving functions have been grouped into five functional groups which are further subdivided into three operational groups. These functional groups are:

- (a) Engine (Rows 15, 16 and 17)
- (b) Liquid Hydrogen (Rows 18, 19 and 20)
- (c) Liquid Nitrogen (Rows 21, 22 and 23)
- (d) Gaseous Hydrogen (Rows 24, 25 and 26)
- (e) Gaseous Helium (Rows 27, 28 and 29)

Operational groups are:

- (a) Compute (Columns A through F)
- (b) Initial Condition (IC) (Columns G through M)
- (c) Relays (Columns N through Z)

2.4.3.3 Logic Command Controls

There are four operational commands that control the TSS in addition to the "Power On-Off" switch located on the front of the logic chassis.

These commands are "Reset, Hold, Compute and Initial Condition." Reset resets the cooldown and engine simulation to their initial conditions; Compute allows the engine to go into the compute mode, excluding the core and reflector groups; and Initial Condition returns the engine to its initial condition. These commands can be operated from the control chassis located in Rack 60 or from the remote operation panel, Rack 01L. The remote

operator selects which of the two stations has control, indicated by the REMOTE/LOCAL light on the logic chassis. The command logic inputs are located at Rows 4 and 5, A through D, of the logic patchboard. The signal levels at these points switch from an open input to ground when each condition is activated. The commands are locally interlocked so that only one command can activate at a time.

2.4.3.4 Emergency Command Controls

Start, SCRAM and emergency shutdown controls are located in rows 4 and 5, E to G. These commands represent external controls that affect the TSS operation. These commands are generated by contact closures or opening and, therefore, a system logic high (ground) must be supplied to the external contact by patching logic high to row 6 H, J, K of the patchboard.

All input logic functions and controls are connected to the logic chassis by connecting the desired driving function in rows 2 and 5 to the associated network input in rows 3 and 6 of the logic patchboard. Any logic driving function can be simulated by connecting logic high (ground) to logic network input in row 3 or 6.

When the logic is not interconnected, it appears as a "false" condition to the logic network.

2.4.3.5 Logic Inputs

There are three types of input commands: logic inputs, control commands, and emergency commands.

2.4.3.6 Logic Input Function

There are 24 logic functions which are generated inside the TSS and fed to the logic patchboard. All functions are located in rows 1 and 2 of the logic patchboard (LPB).

These functions are all generated from relay contact closures located throughout the TSS and represent valve openings (i.e., 50RSV78 located at 1A and 2A) or pressure ratio charges (i.e., $P_{e_3} > P_{13}$ located at 1Z and 2Z). Whenever 50RSV78 valve opens, or pressure P_{e_3} becomes larger than P_{13} within the TSS, the voltage at 1A and 2A or 1Z and 2Z changes from -3 v to ground.

2.5 CHECKOUT

2.5.1 Logic Checkout

The following procedure will exercise the TSS logic and check for functional operation.

Disconnect all patch points on the LPB except patches between rows 5 and 6, A through D (logic controls). Simulate input functions according to Table 3 by connecting the logic input in row 3 to logic high (ground) and depressing the required control button in the proper sequence. Then monitor the output function according to the output table. Errors should be traced according to standard procedures, examining each stage of logic for its proper value until the cause of the error is determined. All logic functions are easily accessible when the logic drawer is pulled out and its chassis cover is removed. Refer to the following Digital Equipment Corporation Drawings: (1) RS-B-R107-2, (2) RS-B-R121, (3) RS-B-W040, and (4) RS-B-R204.

TABLE 3

TSS Logic Checkout Table

To Be Supplied

2.5.2 Logic Outputs

A unique capability of this system is the ability to program the TSS logic to switch control from the master command push-button to individual compute and initial condition switches located in each five-shelf housing. This feature allows a portion of the system to be operated normally from master control, and one or more sections to be under local control for troubleshooting or special tests. This feature is especially important during startup or when modifications are required.

2.5.3 Checkout Mode

The local control switches in each five-shelf housing can be connected to the integrators within the housing by patching row 16 to row 17 instead of 16 to row 15, etc. In addition, the local switch must be patched to the associated patchboard compute and IC buss line.

This is accomplished by patching the desired IC, and IC bus locations together in row 30 and by patching the computer and compute buss together in row 32. No other patching is required.

3. THEORY OF OPERATION

Since the simulation consists of three areas, cooldown and logic, this section shall be divided into those three areas. Section 3.1 shall be engine, 3.2 shall be cooldown discussion, and 3.3 shall be logic discussion.

3.1 ENGINE SIMULATION

3.1.1 Introduction

It is the intent of this and the following section to describe the following information concerning the engine simulation:

- (a) Physically located equipment
- (b) Schematically identify equipment
- (c) Describe peculiar setup procedures and operational checks
- (d) Define equations used for simulation
- (e) Show scaling technique for all equations
- (f) Note applicable reference drawings

Eleven functional groups make up the ETS-1 engine simulation and are interconnected through the analog patchboard. One of these groups, the diluent valve simulation, is not used.

The manner in which these groups operate is controlled through the digital logic chassis which in turn is connected to each functional group through the logic patchboard. These two patchboards provide the means by which each functional group can be isolated and independently operated.

The eleven functional groups that make up the engine simulation are contained in Racks 61A, 62A, and 62B, as shown in Figures 7 and 8.

Figure 7 - Engine Simulator: Front View

Figure 8 - Engine Simulator: Rear View

The following drawings shall be referred to when investigating the setup procedures:

- (a) AGC Drawing 114313
- (b) EAI Drawing C00 004 0226 0A
- (c) EAI Drawing C00 004 0227 0A

It should be noted that there are a few spare parts scattered throughout the hardware layout. These spare parts are identified in the AGC Drawing 1114313.

3.1.2 TPCV Functional Group

3.1.3 Drum Functional Group

3.1.3.1 Setup Procedures

- (a) Verify that all power supply voltages in Rack 62A are at their proper values.
- (b) Verify that all the amplifiers are properly balanced.
- (c) Setting of/or changing potentiometer gains and amplifier limits.
 - (1) Follow procedure outlined in Section 2.4.1 to set the limits. R6 to +0.9 volts and R1 to -7.2 volts.
 - (2) Set R11 to .500 (see Section 2.4.3 for details in setting potentiometer gains).
 - (3) Set R15 to .999. This is simply done by adjusting R15 until OA6206 is identical, except in polarity, to that entering the analog patch point C2.

3.1.4 Diluent Valve Functional Group

3.1.4.1 Setup Procedures

- (a) Verify that all power supply voltages in Rack 62A are at their proper values.
- (b) Verify that all the amplifiers are properly balanced.
- (c) For details in setting or changing potentiometer gains, see Section 2.4.3.

3.1.4.2 Operational Check

A simple static check here is sufficient for verification of circuit operation.

3.1.5 Reactor Kinetics Functional Group

3.1.5.1 Setup Procedures

- (a) Verify that all power supply voltages in Rack 62A are at their proper values.
- (b) Verify that all amplifiers are properly balanced.
- (c) To set or change potentiometer gains, follow procedure outlined in Section 2.4.1.3.

3.1.5.2 Operational Check

Reference Tables 4 and 5.

3.1.6 Reactivity Functional Group

3.1.6.1 Setup Procedures

- (a) Verify that all power supply voltages in Rack 62A are at their proper values.

(b) Verify that all the amplifiers are properly balanced.

(c) To set DFG, refer to Section 2.4.1.2 prior to using the Variable Diode Function Generator Manual.

(d) To set or change potentiometer gains, follow procedure outlined in Section 2.4.1.3.

3.1.6.2 Operational Check

A simple static check here is sufficient for verification of circuit operation. Reference I.C. and 100% Power Tables.

TABLE 4
OPERATING VOLTAGES FOR THE ENGINE
SIMULATION IN ITS IC CONDITION

<u>Amp No.</u>	<u>Voltage</u>	<u>Amp No.</u>	<u>Voltage</u>	<u>Amp No.</u>	<u>Voltage</u>
62AI-1	- .02	62AIII-5	+10.41	62AV-1	-11.86
62AI-2	+ .005	62AIII-6	-10.41	62AV-2	+ 1.00
62AI-5	+ .019	62AIII-7	0.000	62AV-5	- 3.66
62AI-6	- .003	62AIII-8	0.000	62AV-6	+11.86
62AI-9	- 1.43	62AIII-11	+ 0.002	62AV-9	0.00
62AI-10	- .020	62AIII-12	0.000	62AV-10	- 0.66
62AI-13	+10.00	62AIII-15	- 0.260	62AV-13	0.00
62AI-14	+ 1.42	62AIII-16	0.000	62AV-14	- 0.09
62AI-15	-11.70	62AIII-19	0.000		
62AI-16	+ .147	62AIII-20	0.000		
62AI-19	+ 9.9				
62AI-20	-10.0	62AIV-3	- .533		
		62AIV-4	+ .639		
62AII-1	- 2.868	62AIV-7	- 1.000		
62AII-2	- .013	62AIV-8	+ 1.19		
62AII-5	+ .005	62AIV-11	- 1.004		
62AII-6	.000	62AIV-12	+ 1.19		
62AII-7	.000	62AIV-17	+ 1.00		
62AII-8	+ 2.870	62AIV-18	+ .534		
62AII-11	0.000				
62AII-12	+ 0.015				

TABLE 4 (cont.)

<u>Amp No.</u>	<u>Voltage</u>	<u>Amp No.</u>	<u>Voltage</u>	<u>Amp No.</u>	<u>Voltage</u>
62BI-1	- 2.09	62BIII-5	+10.26	62BV-1	+ 0.71
62BI-2	+ 3.25	62BIII-6	-10.36	62BV-2	- 0.58
62BI-7	- 0.45	62BIII-7	+ 0.09	62BV-5	0.00
62BI-8	+ 0.11	62BIII-8	- 0.09	62BV-6	0.00
62BI-11	+ 0.48	62BIII-11	0.00	62BV-7	- 0.02
62BI-12	+ 2.09	62BIII-12	0.10	62BV-8	- 0.06
62BI-13	0.00			62BV-11	+ 0.57
62BI-14	0.00	62BIV-1	+ 0.62	62BV-12	0.00
62BI-17	- 0.49	62BIV-2	+ 0.64	62BV-13	0.00
62BI-18	- 3.25	62BIV-3	+ 0.64	62BV-14	+ 0.85
62BI-19	+ 0.54	62BIV-4	+ 0.66	62BV-17	0.00
62BI-20	- 2.08	62BIV-7	+ 0.67	62BV-18	- 0.02
		62BIV-8	0.00		
62BII-1	- 1.60	62BIV-9	0.68		
62BII-2	+ 1.60	62BIV-10	0.68		
62BII-5	+ 0.03	62BIV-13	0.68		
62BII-6	+ 0.69	62BIV-14	0.68		
62BII-7	0.00				
62BII-8	- 0.06				
62BII-11	+ 0.06				
62BII-12	+ 1.25				
62BII-15	- 1.22				
62BII-16	+ 0.12				

TABLE 4 (cont.)

<u>Amp No.</u>	<u>Voltage</u>	<u>Amp No.</u>	<u>Voltage</u>	<u>Amp No.</u>	<u>Voltage</u>
61AI-1	+ 1.00	61AIII-5	+10.28	61AV-3	0.00
61AI-2	+ 0.96	61AIII-6	-10.26	61AV-4	-11.31
61AI-3	- 3.25	61AIII-9	+ 0.59	61AV-7	- 0.64
61AI-4	+10.90	61AIII-10	+ 0.18	61AV-8	+ 0.64
61AI-7	-10.90	61AIII-13	- 3.46	61AV-9	+ 0.72
61AI-8	+ 0.23	61AIII-14	- 0.48	61AV-10	+ 0.24
61AI-11	- 0.30	61AIII-17	- 1.45	61AV-13	- 0.07
61AI-12	0.00	61AIII-18	+ 1.45	61AV-14	+ 0.07
61AI-17	- 0.08				
61AI-18	+ 0.96	61AIV-1	+ 3.46		
		61AIV-2	- 0.59		
61AII-1	+ 0.82	61AIV-5	- 0.21		
61AII-2	+ 1.20	61AIV-6	+ 0.21		
61AII-5	+ 0.50	61AIV-7	+ 1.32		
61AII-6	0.00	61AIV-8	+ 0.14		
61AII-7	- 0.61	61AIV-13	+ 0.14		
61AII-8	+11.82	61AIV-14	- 1.43		
61AII-9	- 1.20	61AIV-17	- 0.18		
61AII-10	- 0.50	61AIV-18	+ 1.43		
61AII-13	- 0.23	61AIV-19	0.00		
61AII-14	-11.98	61AIV-20	+ 0.48		
61AII-15	+ 1.96				
61AII-16	+ 5.92				

TABLE 5

100% STEADY STATE VOLTAGES FOR THE ENGINE SIMULATION

<u>Amp No.</u>	<u>Voltage</u>	<u>Amp No.</u>	<u>Voltage</u>	<u>Amp No.</u>	<u>Voltage</u>
62AI-1	+ 6.00	62AIII-5	+10.36	62AV-1	0.00
62AI-2	- 2.90	62AIII-6	-10.40	62AV-2	+ 0.99
62AI-5	+ 6.05	62AIII-7	0.00	62AV-5	0.00
62AI-6	- 2.92	62AIII-8	0.00	62AV-6	0.00
62AI-9	+ 7.94	62AIII-11	- 4.84	62AV-9	+ 9.61
62AI-10	- 3.88	62AIII-12	+ 4.84	62AV-10	+10.76
62AI-13	+ 0.16	62AIII-15	+ 9.59	62AV-13	0.00
62AI-14	- 7.94	62AIII-16	0.00	62AV-14	- 9.62
62AI-15	0.00	62AIII-19	+ 5.00		
62AI-16	+ 0.12	62AIII-20	- 5.00		
62AI-19	+ 0.05				
62AI-20	- 0.21	62AIV-3	- 0.51		
		62AIV-4	0.00		
62AII-1	- 2.86	62AIV-7	- 0.88		
62AII-2	- 0.11	62AIV-8	0.00		
62AII-5	0.00	62AIV-11	- 0.99		
62AII-6	0.00	62AIV-12	0.00		
62AII-7	0.00	62AIV-17	+ 0.86		
62AII-8	+ 2.86	62AIV-18	+ 0.51		
62AII-11	0.00				
62AII-12	+ 0.02				

TABLE 5 (cont.)

<u>Amp No.</u>	<u>Voltage</u>	<u>Amp No.</u>	<u>Voltage</u>	<u>Amp No.</u>	<u>Voltage</u>
62BI-1	- 0.48	62BIII-5	+10.28	62BV-1	- 2.65
62BI-2	+ 2.03	62BIII-6	-10.42	62BV-2	+ 6.28
62BI-7	- 0.19	62BIII-7	+ 9.62	62BV-5	+ 8.38
62BI-8	- 0.37	62BIII-8	- 9.87	62BV-6	- 7.02
62BI-11	+ 1.38	62BIII-11	- 0.47	62BV-7	+ 6.22
62BI-12	+ 0.49	62BIII-12	+10.95	62BV-8	- 6.22
62BI-13	0.00			62BV-11	- 6.27
62BI-14	0.00	62BIV-1	-11.21	62BV-12	+ 6.69
62BI-17	- 1.38	62BIV-2	-11.37	62BV-13	+ 3.00
62BI-18	- 2.02	62BIV-3	-11.23	62BV-14	+ 5.87
62BI-19	+ 0.45	62BIV-4	-11.27	62BV-17	- 8.37
62BI-20	- 1.75	62BIV-7	-11.26	62BV-18	+ 3.57
		62BIV-8	+ 9.00		
62BII-1	-11.91	62BIV-9	-11.34		
62BII-2	+11.91	62BIV-10	-11.19		
62BII-5	+ 9.19	62BIV-13	-11.24		
62BII-6	+ 3.04	62BIV-14	-11.34		
62BII-7	0.00				
62BII-8	- 9.14				
62BII-11	+ 9.15				
62BII-12	+ 2.18				
62BII-15	- 1.99				
62BII-16	- 0.22				

TABLE 5 (cont.)

<u>Amp No.</u>	<u>Voltage</u>	<u>Amp No.</u>	<u>Voltage</u>	<u>Amp No.</u>	<u>Voltage</u>
61AI-1	- 7.49	61AIII-5	+10.30	61AV-3	+ 6.10
61AI-2	+ 0.60	61AIII-6	-10.26	61AV-4	-11.34
61AI-3	- 2.03	61AIII-9	+ 6.11	61AV-7	- 0.85
61AI-4	+ 1.05	61AIII-10	+ 5.43	61AV-8	+ 0.85
61AI-7	- 1.05	61AIII-13	- 8.92	61AV-9	+ 3.87
61AI-8	+ 3.36	61AIII-14	+ 7.35	61AV-10	+ 7.56
61AI-11	- 3.37	61AIII-17	- 7.48	61AV-13	- 8.86
61AI-12	- 2.50	61AIII-18	+ 7.48	61AV-14	+ 8.86
61AI-17	+ 0.87				
61AI-18	+ 4.97	61AIV-1	+ 9.04		
		61AIV-2	- 6.30		
61AII-1	- 6.49	61AIV-5	- 5.99		
61AII-2	+ 7.96	61AIV-6	+ 5.65		
61AII-5	+ 9.00	61AIV-7	+ 6.43		
61AII-6	0.00	61AIV-8	+ 6.60		
61AII-7	+ 7.73	61AIV-13	- 5.08		
61AII-8	+ 2.62	61AIV-14	- 6.80		
61AII-9	- 7.96	61AIV-17	- 5.43		
61AII-10	- 9.00	61AIV-18	+ 6.93		
61AII-13	- 3.36	61AIV-19	+10.07		
61AII-14	- 1.73	61AIV-20	- 7.35		
61AII-15	- 0.79				
61AII-16	+ 5.93				

The two diode function generators (DFG) can be conveniently checked using Figure 9 during either the static check or separately in the DFG setup slot.

3.1.7 Decay Heat Functional Group

3.1.7.1 Setup Procedures

- (a) Verify that all power supply voltages in Rack 62B are at their proper values.
- (b) Verify that all the amplifiers are properly balanced.
- (c) To set or change potentiometer gains, follow procedure outlined in Section 2.4.1.3.

3.1.7.2 Operational Check

- (a) Input - Output DC Gain Check

The input-output DC gain must agree with that required of the transfer function. In this case, it is equal to 1.0626. Reference Tables 4 and 5.

3.1.8 Nuclear Instrumentation Functional Group (Ref. AGC Dwg 1114313 Sh. 7)

3.1.8.1 Setup Procedures

- (a) Verify that all power supply voltages in Rack 62B are at their proper values.
- (b) Verify that all the amplifiers are properly balanced.
- (c) To set or change potentiometer gains, follow procedure outlined in Section 2.4.1.3.

Figure 9 - Reactivity Profile for Drums

(d) To set or change amplifier limits, follow procedure outlined in Section 2.4.1.1.

(e) To set DFG, refer to Section 2.4.1.2 prior to using the Variable Diode Function Generator Manual.

3.1.8.2 Operational Check

A simple static check here is sufficient for verification of circuit operation. Reference Tables 4 and 5.

The diode function generator can be conveniently checked using Figure 10 during either the static or separately in the DFG setup slot.

3.1.9 Reflector Functional Group (Ref AGC Dwg. 1114313 Sh. 4)

3.1.9.1 Setup Procedures

(a) Verify that all power supply voltages in Rack 62B are at their proper values.

(b) Verify that all the amplifiers are properly balanced.

(c) To set or change potentiometer gains, follow procedure outlined in Section 2.4.1.3.

(d) To set DFG, refer to Section 2.4.1.2 prior to using the Variable Diode Function Generator Manual.

3.1.9.2 Operational Check

A simple static check here is sufficient for verification of circuit operation. Reference Tables 4 and 5.

Figure 10 - Linear to Nonlinear Sawtooth Conversion Curve

The diode function generator can be conveniently checked using Figure 11 during either static check or separately in the DFG setup slot.

3.1.10 Pump Functional Group (Ref. AGC Dwg 1114313 Sh. 11)

3.1.10.1 Setup Procedures

(a) Verify that all power supply voltages in Rack 62B are at their proper values.

(b) Verify that all the amplifiers are properly balanced.

(c) To set or change potentiometer gains, follow procedure outlined in Section 2.4.1.3.

(d) To set DFG, refer to Section 2.4.1.2 prior to using the Variable Diode Function Generator Manual.

3.1.10.2 Operational Check

A simple static check here is sufficient for verification of circuit operation. Reference Tables 4 and 5.

The diode function generator can be conveniently checked using Figure 12 during either static check or separately in the DFG setup slot.

3.1.11 Core Functional Group

3.1.11.1 Setup Procedures

(a) Verify that all power supply voltages in Rack 61A are at their proper values.

Figure 11 - Reflector Heat Capacity Curve

Figure 12 - Pressure Drop Ratio Profile Across TPCV

(b) Verify that all the amplifiers are properly balanced.

(c) To set or change potentiometer gains, follow procedure outlined in Section 2.4.1.3.

(d) To set DFG, refer to Section 2.4.1.2 prior to using the Variable Diode Function Generator Manual.

3.1.11.2 Operational Check

A simple static check here is sufficient for verification of circuit operation. Reference Tables 4 and 5.

The diode function generator can be conveniently checked using Figure 13 during either static check or separately in the DFG setup slot.

3.1.12 Flow Functional Group

3.1.12.1 Setup Procedures

(a) Verify that all power supply voltages in Rack 61A are at their proper values.

(b) Verify that all the amplifiers are properly balanced.

(c) To set or change potentiometer gains, follow procedure outlined in Section 2.4.1.3.

Figure 13 - Core Heat Capacity Curve

3.1.12.2 Operational Check

Reference Tables 4 and 5.

3.1.13 Interconnection of Functional Groups

Each functional group schematic shows patch point interconnections. Every input patch point, except spares, is shown with its connection to a particular source (output) patch point. Likewise, every output patch point, except spares, is shown with its connection to some input patch point. Consequently, it is possible using the Computer Diagram AGC 1114313 to interconnect all of the engine functional groups.

In addition to this, a block diagram has been made (EAI Drawing No. 04.00591) which shows all the analog patch point interconnections for the eleven engine simulation functional groups.

3.1.14 Theory of Operation

The equations used in defining the engine simulation are listed in Section 3.1.15. AGC Drawing 1114513 LH₂ Engine Flow Diagram will be helpful in comparing the simulation with the hardware.

3.1.14.1 General Theory

The simulator was designed to cover twelve decades of log power. It covers the range from startup of one-one thousandth watt power to full power of 1130 megawatts. A source term is also simulated whose contribution to the simulation disappears as power increases (AMP 6227). Due to the twelve decade logarithmic nature of the reactor power buildup, it was necessary to separate the activation of the engine simulation from that of

the reactor kinetics. The reactor kinetics were designed to simulate over the entire range of twelve decades with log power scaled to eight-tenths of a volt per decade. At full power, therefore, LnN (low power) reads $12 \times (.8)$ or 9.6 volts. The net effect of the log power output is the same as that of plotting volts output versus log power on semi-log power. This plot is a straight line. Therefore, the log power output is a straight line or linear voltage output, or, in other words, eight-tenths volt per decade. Linear power is the anti-log of log power and, therefore, its output is truly logarithmic. Because of this and also because linear power is an input to the engine equations, it was necessary to simulate only two decades of power for linear power and two decades of engine simulation. This simulation is activated by the start reactor button located on the CTE console. This means that the linear power and engine simulation do not go into a compute situation until 1% power is arrived at. For this reason, the reactor kinetics are normally brought up to 1% power, and after this point is reached, the start engine button on the CTE console activates the engine and linear power simulation. The technique used to keep the engine simulation in an IC condition up to 1% power was to keep the two key integrators in the simulation in an IC condition until the start engine button was pushed, at which time, the two integrators (H_C and H_R - core and reflector groups) operate relays were energized. At the same time, K6 relay in the reactor kinetics circuit was energized and permitted the linear power to start simulating. Potentiometer R9 feeding amplifier 6241 in the linear power circuit is a bias control which is set to bias out the first 10 decades of reactor kinetics simulation.

It will be noted that there really are only two inputs into the engine simulation from the outside world drum demand (θ_{DD}) and turbine power control valve demand (θ_{TPCVD}). All the other parameters are computed by the simulator and are sent to the rest of the TSCS.

3.1.14.2 Reactor Kinetics Functional Group

A three-delay group simulation is also included in the reactor kinetics simulation.

3.1.14.3 Decay Heat Functional Group

The purpose of this group is to simulate additional power generation due to heating effect of the engine. The linear power produced by this group is roughly seven percent of the total power and is added to the total power prior to entering the engine simulation.

3.1.14.4 Nuclear Instrumentation Functional Group

As was described earlier, the engine simulation consists of twelve decades of log power simulation at eight-tenths volt per decade. The Engine Control System, however, requires an eight decade simulation at one and one quarter volts per decade. Pot R15 associated with Amp 6256 is used for the gain change. Pot R17 associated with the same amplifier is used for nulling out the first four decades so that only the last eight decades are used. By the same token, the linear power scaling throughout the system is ten decades of power. Potentiometer R16 associated with Amp 6259 is used for nulling out the first two decades and Potentiometer R14 associated with the same amplifier is used for setting the ramp voltage to one volt per decade. Amplifier 6257 output varies linearly from zero to ten volts per decade after the first two decades.

The linear power range generator is used to trigger the proper ranging relays in the picoammeter and microammeters and it is also used to generate a staircase voltage which is used as a nulling voltage in Amplifier 6257.

3.1.14.5 Core Functional Group

In the core functional group, the reason for generating approximate chamber temperature ($\sim T_8/500$) is to adapt from the 0 to 5000° scaling of the computer to the 500 to 4850° meter face sealing.

3.1.14.6 Flow Functional Group

The flow functional group under normal engine run conditions requires little explanation since it is merely a simulation of the engine equations as described earlier. However, under cooldown conditions, the interface between cooldown and the engine occurs in the flow group.

As far as cooldown is concerned, the engine simulation is designed to function for the four different cooldown parameters (LH_2 , LN_2 , GH_2 and GHe). Since the universal gas constant for LH_2 , LN_2 and GH_2 are similar, the same potentiometer settings as used for LH_2 were also used for LN_2 and GH_2 throughout. The only gas requiring a different set of potentiometer settings was GHe . As can be seen on Sheets 9 and 10 of AGC Drawing 1114313, two sets of relays for cooldown are used throughout, namely, K1 and K2. In normal engine run conditions, these relays are de-energized. However, when a cooldown situation exists, the K2 relays always pick up and stay picked up. The K1 relays pick up only when the GHe phase cooldown is being experienced.

It will also be observed that under a cooldown situation the engine equations for W_P^2 and W_P no longer exist because the K2I contact prior to Amplifier 6125 is opened. This occurs because flow is now controlled by the cooldown simulation. It will be noted that W_P used in generating $P_6/100$ is switched in from the cooldown. It will also be noted that the simulation for $-P_3/100$ changes appreciably under this condition. All the normal engine terms feeding $-P_3/100$ are switched out at this time, and the P_6 and W_P^2 term from cooldown are switched in on the basis of the new equation which defines $-P_3/100$ under these conditions.

3.1.14.7 TPCV Functional Group

The TPCV simulation is a three amplifier simulation of the second order equation describing the valve. The open and close velocity limits for this valve are set at $\pm 360^\circ/\text{sec}$.

3.1.14.8 Drum Functional Group

The drum simulation is a three amplifier simulation of the second order equation describing the valve. The open and close velocity limits for this valve are set at $+45^\circ$ and $-360^\circ/\text{sec}$ respectively.

3.1.14.9 Reactivity Functional Group

The reactivity group contains the source term (Amp 6227) whose output is added to those functions making up the total reactivity. The output of this group is a total reactivity term which is used as an input to the reactor kinetics group.

3.1.14.10 Reflector Functional Group

This group includes the reflector thermodynamics simulation. The reader's attention is directed to Amplifier 6276 whose operate and initial condition relay are shown on the bottom of the diagram.

Integrator 6276 will not go into a compute condition until the K_0 relay is energized. This is energized when the "Start Engine" button is pushed on the console.

3.1.14.11 Pump Functional Group

This group simulates such functions as pump and turbine torque and turbine speed.

3.1.14.12 List of Figures

Tables 4 and 5 are included to show the amplifier voltages at IC conditions and at 100% power. These tables should be very helpful in troubleshooting the equipment.

A list of patchable input and output functions to the engine simulation are shown in Table 6.

A list of engine constants at 100% power is included in Table 7.

TABLE 6

LIST OF INPUT AND OUTPUT FUNCTIONS
AND THEIR PATCHBOARD LOCATIONS

	<u>Function</u>	<u>Patchboard</u>
1.	$+ \theta_{\text{TPCV}_D} / 9$	S2
2.	$+ \theta_{\text{TPCV}_M} / 9$	R1
3.	$- \theta_{DD} / 18$	S5
4.	$+ \theta_D \text{ OVER IDE} / 18$	R18
5.	$+ \theta_D \text{ MEASURED} / 18$	Q2
6.	+ Log Count Rate	R9
7.	- Log Count Rate	R8
8.	8 Decade Log	R7
9.	1 Decade Linear Power	R10
10.	PSOV INDICATOR	R19
11.	$P_{e3} / 100$	R20
12.	PSOV	S24
13.	$W_P / 20$	R21
14.	$P_8 / 75$	R23
15.	$T_3 / 75$	R22
16.	$\theta_{\text{TPCV}} / 9$	S1
17.	ST 1/2 + 1/200	R15
18.	$\sim T_8 / 500$	R6
19.	P_{15}	R3
20.	$T_8 / 500$	R5
21.	ST 26/500	R17

TABLE 7
SIMULATED XE ENGINE PARAMETERS
(FULL POWER)

Overall Engine Thrust, lb	46,552
Main Exhaust Chamber Thrust, lb	44,352
Turbine Exhaust Nozzle Thrust, lb	2,200
Overall Engine Specific Impulse, sec	663
Chamber Specific Impulse, sec	632
Turbine Nozzle Specific Impulse, sec	31.3
Turbine Power Control Valve Position, degrees	43.5
Reactor Power Level, mw	1,130
Turbine Speed, RPM	21,000

<u>Station</u>	<u>Flow lb/sec</u>	<u>Psia</u>	<u>Temp °R</u>
Tank	77.2	69.5	36.5
Pump Inlet, 2	77.2	36	36.5
Pump Outlet, 3	76.0	930	44.5
Nozzle Manifold Inlet	76.0	904	97.5
Nozzle Outlet, 5	76.0	737	139
Reflector Outlet, 6	76.0	667	260
Core Outlet, 7	21.5	550	4090
Nozzle Chamber, 8	70.2	550	4090
TPCV Inlet	5.83	541	1140
TPCV Outlet	5.83	413	1140
Turbine Inlet	5.83	412	1140
Turbine Outlet	7.03	114	863

3.1.15 Equations and Deviations for Engine Simulation

3.1.15.1 Equations Defining Engine Simulation

$$1. \quad \frac{\theta_{Dm}}{\theta_{DD}} = \frac{3}{S+3}$$

$$2. \quad \theta_{TPCV_{Dm}} = \frac{K_{\theta_{TPCV_D}}}{S (1 + 0.01S)(1 + 0.0045S)(1 + 0.0025S)^2}$$

$$3. \quad 10 X_D (\text{Diluent}) = 10 X_m (\text{Diluent})$$

$$4. \quad \sigma K_{Total} = \sigma K_D - \sigma K_t + \sigma K_{\rho} - K_{37} \quad \text{where } K_{37} = 4.5 \text{ Dollars}$$

$$5. \quad \sigma K_D = K_9 \sin^2 \left[\frac{\theta_D}{2} \right] \quad \text{where } K_9 = 9$$

$$6. \quad \sigma K_t = .0015 (\phi_{c1} - 520^\circ R)$$

$$7. \quad \sigma K_{\rho} = \frac{2.25 \dot{W}_c}{\sqrt{T_8}}$$

$$8. \quad M = \frac{\sigma K^1 - \beta_{Total}}{\ell^*} + \sum_{i=1}^3 \tau_i V_i + W \quad \ell^* = 2.5 \times 10^{-5}$$

$$\text{where } \sigma K^1 = \beta_{Total} \sigma K_{Total}$$

$$\beta_{Total} = \beta_1 + \beta_2 + \beta_3$$

$$9. \quad \dot{V}_1 = \frac{\beta_1}{\ell^*} - (\tau_1 + M) V_1 \quad \text{where } \beta_1 = 1.956 \times 10^{-3}$$

$$\tau_1 = .0222$$

$$10. \quad \dot{V}_2 = \frac{\beta_2}{\ell^*} - (\tau_2 + M) V_2 \quad \beta_2 = 4.64 \times 10^{-3}$$

$$\tau_2 = .2133$$

$$11. \quad \dot{V}_3 = \frac{\beta_3}{\ell^*} - (\tau_3 + M) V_3 \quad \beta_3 = 1.2 \times 10^{-3}$$

$$\tau_3 = 2.614$$

$$12. \quad \eta_{\text{Total}} = \frac{0.65 (1 + 31.6S)}{(1 + 3.52S) (1 + 50S)} \eta_R + \eta_R \quad \text{where } \eta_R = \eta_{\text{Reactor}}$$

$$13. \quad \ln \eta_R = \int M \, dt$$

$$14. \quad 5 \log_{10} \eta_R = 2.17 \int M \, dt$$

$$15. \quad 3.48 \int M \, dt = \frac{.8 \, \text{Ln } \eta_R}{\text{Ln } 10}$$

$$16. \quad W_n = \frac{8.17 \, P_8}{\sqrt{T_8}}$$

$$17. \quad \rho_8 = 0.0575 \int (\dot{W}_c - 1.017 \, \dot{W}_n) \, dt$$

$$18. \quad P_8 = 767/144 \, \rho_8 \, T_8 = 5.32 \, \rho_8 \, T_8$$

$$19. \quad (\dot{W}_c)^2 = 43.67 (P_6 - P_8)$$

$$20. \quad P_6 = 26.6 \int (\dot{W}_P - 1.056 \dot{W}_c) dt$$

$$21. \quad \dot{W}_P^{.2} = 21.98 (P_3 - P_6)$$

$$22. \quad T_3 = T_2 + 1.84 \times 10^{-8} N^2 + 4.31 \times 10^{-6} \dot{W}_P N - 6.82 \times 10^{-4} \dot{W}_P^{.2}$$

$$23. \quad P_3 = P_2 + 1.5 \times 10^{-6} N^2 + 3.5 \times 10^{-4} \dot{W}_P N - 5.56 \times 10^{-2} \dot{W}_P^{.2}$$

$$24. \quad M_P = 76/21,000 \left[9.07 \times 10^{-4} N^2 - .0667 N \dot{W}_P + 15.95 \dot{W}_P^{.2} \right]$$

$$25. \quad \dot{N} = 75 (M_T - M_P)$$

$$26. \quad M_T = 3.47 P_{15}$$

$$27. \quad P_{15}/P_8 = f(\theta_{\text{TPCV}})$$

$$28. \quad \dot{H}_R = 190 \eta_{\text{Total}} - 51.2 \dot{W}_P \left[\phi_R - (T_5 + T_6)/2 \right]$$

$$29. \quad \phi_R = f(H_R)$$

$$30. \quad T_5 = T_3 + .0222 T_8$$

$$31. \quad T_6 = T_5 + 14 \left[\phi_R - (T_5 + T_6)/2 \right]$$

$$32. \quad \dot{H}_c = 10,800 \eta_{\text{Total}} - 44 \dot{W}_c \left[\phi_c - (T_6 + T_8)/2 \right]$$

$$33. \quad \phi_{c1} = f(H_c)$$

$$34. \quad T_8 = T_6 + 11.6 \left[\phi_{c1} - (T_6 + T_8)/2 \right]$$

$$35. \quad T_{tr} = K_1 \phi_{SG}^{-K_2} \dot{W}_C$$

$$36. \quad d \phi_{SG}/dt = .23 (\phi_{c.2} + 4.2 \eta - \phi_{SG})$$

$$37. \quad \phi_{SG_m} / \phi_{SG} = 1/(1 + S/8.8)$$

$$38. \quad \text{Station 26} = T_8 - 400^\circ R$$

$$39. \quad \text{Station 20} = 20/26 (ST_{26} - T_6) + T_6$$

GHe Cooldown

$$40. \quad \dot{W}_n = 20 \frac{P_8}{\sqrt{T_8}}$$

$$41. \quad P_8 = .0288 \int (\dot{W}_c - 1.017 \dot{W}_n) dt$$

$$42. \quad P_6 = 13.3 \int (\dot{W}_p - 1.056 \dot{W}_c) dt$$

$$43. \quad P_8 = 384/144 \rho_8 T_8 = 2.67 \rho_8 T_8$$

$$44. \quad \dot{W}_c^2 = 12.5 (P_6 - P_8)$$

$$45. \quad \dot{W}_p^2 = 3.3 (P_3 - P_6)$$

3.1.15.1.1 Scaled Values for TSS Engine Simulation

<u>Function</u>	<u>Scaled</u>
ϕ_{TPCV}	100°
ϕ_{Drums}	200°
T_{13}	2000°
σ_K	5
V_1	70,500
V_2	8700
V_3	184
M	100
Lnn	.8 V/Decade
η	% Linear Power; 10 V = 100%
T_8	5000°
P_8	1000 lb/in. ²
$\dot{W}_c$	100 lb/sec
$\dot{W}_n$	115 lb/sec
$P_{.6}$	1000 lb/in. ²
$\dot{W}_P$	100 lb/sec
M_P	2000 ft-lbs
N	25,000 RPM
M_T	3,330 ft-lbs
P_{PSOV_M}	1000 lb/in. ²
T_3	560°R
P_3	1000 lb/in. ²
H_R	250,000 BTU
ϕ_R	1000°R
T_5	1000°R
T_6	1000°R
H_c	6×10^6 BTU
ϕ_c	5000°R
T_{trR}	2000°R
T_8	5000°R

3.1.15.2 Scaling of Computer Schematics for the TSS Analog 10 Volt Simulation

1, 2, 3 and 4. (See AGC Drawing 1114313, sheet 5)

$$\sigma K_{\text{total}} = \sigma K_D - \sigma K_t + \sigma K_\rho - K_{37}$$

$$\text{where} \quad \sigma K_D = K_9 \sin^2 \left(\frac{\theta}{2} \right) \quad K_{37} = 4.5 \text{ Dollars}$$

$$\sigma K_t = .0015 (\phi_{c1} - 520^\circ R) \quad K_9 = 9$$

$$\sigma K_\rho = 2.25 \frac{W_c}{\sqrt{T_8}}$$

$$\text{Gain A} = (2.25 \times 2)/7.07 = .636$$

$$\text{Gain B} = 1/12 \times (81 \times 2)/100 = 162/1200 = .135$$

$$\text{Gain C} = 11/12 \times (81 \times 2)/100 = 1780/1200 = 1.490$$

$$\text{Gain D} = .75 \times 2 = 1.50$$

$$\text{Gain E} = (4.5 \times 2)/10 = .900$$

$$\text{Gain F} = \frac{(.0015)(520)}{.75(10)} = .104$$

NOTE: Gain B simulates one drum. Gain C simulates eleven drums.

$$5. \quad M = \frac{\sigma K^1 - \beta_{\text{Total}}}{\ell^*} + \sum_{i=1}^3 \tau_i V_i = W \quad \text{where } \sigma K^1 = \beta_{\text{Total}} \sigma K_{\text{Total}}$$

$$\beta_{\text{Total}} = \beta_1 + \beta_2 + \beta_3$$

$$\beta_{\text{Total}} = 7.796 \times 10^{-3}$$

$$\ell^* = 2.5 \times 10^{-5}$$

$$\tau_1 = .0222$$

$$\tau_2 = .2133$$

$$\tau_3 = 2.614$$

$$M = \frac{7.8 \times 10^{-3} \sigma K}{2.5 \times 10^{-5}} \frac{7.8 \times 10^{-3}}{2.5 \times 10^{-5}} + .0222 V_1 + .2133 V_2 + 2.614 V_3$$

$$M = 312 \sigma_{\text{Total}} - 312 + .0222 V_1 + .2133 V_2 + 2.614 V_3$$

(See AGC Drawing 1114313, Sheet 8)

$$\text{Gain A} = 312/(10 \times 10) = 3.12$$

$$\text{Gain B} = 312/(10 \times 1.57) = 20$$

$$\text{Gain C} = (7050 \times .0222)/10 = 15.7$$

$$\text{Gain D} = (870 \times .2133)/10 = 18.6$$

$$\text{Gain E} = (18.4 \times 2.614)/10 = 4.8$$

$$\text{Gain F} = 10/(10 \times 20) = .05$$

$$\text{Gain G} = 1.57/2 = .782$$

(See Sheet 5 for this gain setting)

$$6. \quad \dot{V}_1 = \frac{\beta_1}{\ell^*} - (\tau_1 + M) V_1 \quad \text{where } \beta_1 = 1.956 \times 10^{-3}$$

(Slow Delay Group)

$$\tau_1 = .0222$$

(See AGC Drawing 1114313, Sheet 8)

$$\ell^* = 2.5 \times 10^{-5}$$

$$\dot{V}_1 = \frac{1.956 \times 10^{-3}}{2.5 \times 10^{-5}} - (.0222 + M) V_1$$

$$\text{or } \dot{V}_1 = 78.5 - .0222 V_1 - M V_1$$

$$\text{Pot R5} = 78.5 / (10 \times 7050) = 78.5 / 70,500 = .0011$$

$$\text{Pot R7} = .0222 / 7050 \times 7050 = .0222$$

The IC pot is set as follows at IC $\dot{V}_1 = M = 0$

$$\frac{\beta_1}{\ell^*} = \tau_1 V_1 \text{ or } 78.5 = .0222 V_1$$

or $V_1 = 3900$; Since V_1 is scaled to 70,500

$$\text{then IC Gain} = 3900 / 70,500 = .055 = \text{Pot R}_3$$

$$7. \quad \dot{V}_2 = \frac{\beta_2}{\ell^*} - (\tau_2 + M) V_2 \quad \text{Where } \beta_2 = 4.64 \times 10^{-3}$$

(Second Delay Group)

$$\tau_2 = .2133$$

(See AGC Drawing 1114313, Sheet 8)

$$\ell^* = 2.5 \times 10^{-5}$$

$$\dot{V}_2 = \frac{4.64 \times 10^{-3}}{2.5 \times 10^{-5}} - (.2133 + M) V_2$$

$$\dot{V}_2 = 186 - .2133 V_2 - M V_2$$

$$\therefore \text{Pot R13} = 186 / (10 \times 870) = .0213$$

$$\therefore \text{Pot R15} = .2133 / 870 \times 870 = .2133$$

To set IC pot: $\dot{V}_2 = M = 0$

$$\therefore \frac{\beta_2}{\ell^*} = \tau_2 V_2 \text{ or } 186 = .2133 V_2 \text{ or } V_2 = 870$$

Since V_2 is scaled to 8700

$$\text{IC Gain} = 870/8700 = .100 = \text{Pot } R_{11}$$

$$8. \quad \dot{V}_3 = \frac{\beta_3}{\ell^*} - (\tau_3 + M) V_3 \quad \text{Where } \beta_3 = 1.2 \times 10^{-3}$$

(Fast Delay Group)

$$\tau_3 = 2.614$$

(See Sheet 8, AGC Drawing 1114313)

$$\ell^* = 2.5 \times 10^{-5}$$

$$\dot{V}_3 = \frac{1.2 \times 10^{-3}}{2.5 \times 10^{-5}} - (2.614 + M) V_3$$

$$\text{or } \dot{V}_3 = 48 - 2.614 V_3 - M V_3$$

$$\text{Pot } R_{20} = 48/(10 \times 18.4) = .261$$

$$\text{Pot } R_{22} = 2.614/18.4 \times 18.4 = 2.614$$

To set IC gain, $\dot{V}_3 = M = 0$ at IC

$$48 = 2.614 V_3 \text{ or } V_3 = 18.4$$

Since V_3 is scaled to 184, then IC gain = $18.4/184 = .100 = \text{Pot } R_{11}$

$$9. \quad \eta_{\text{Decay Heat}} = \frac{.065 (1 + 31.6S)}{(1 + 3.52S) (1 + 50S)} \quad (\text{see AGC Drawing 1114313, Sheet 14})$$

Now separate into partial functions:

$$\frac{.065 (1 + 31.6S)}{(1 + 3.52S)(1 + 50S)} = \frac{A}{1 + 3.52S} + \frac{B}{1 + 50S}$$

$$A = \frac{.065 (1 + 31.6S)}{1 + 50S} \quad S = -\frac{1}{3.52} = -.284$$

$$A = \frac{.065 (1-9)}{1 - 14.2} = \frac{.51}{.32} = .039$$

$$B = \frac{.065 (1 + 31.6S)}{1 + 3.52S} \quad S = -\frac{1}{50} = -.02$$

$$B = \frac{.065 (1 - .632)}{1 - .07} = \frac{.065 (.368)}{.93} = .026$$

$$\therefore \frac{.065 (1 + 31.6S)}{(1 + 3.52S)(1 + 50S)} = \frac{.039}{1 + 3.52S} + \frac{.026}{1 + 50S}$$

$$\eta_{\text{Decay Heat}} = \frac{\eta_{\text{Reactor}} \times .039}{1 + 3.52S} + \frac{\eta_{\text{Reactor}} \times .026}{1 + 50S}$$

Solving each term separately:

$$\eta_{\text{DH}} = \frac{\eta_{\text{R}} (.039)}{1 + 3.52S}$$

$$\dot{\eta}_{\text{DH}} = \frac{.039 \eta_{\text{R}} - \eta_{\text{DH}}}{3.52}$$

$$= .0111 \eta_{\text{R}} - .284 \eta_{\text{DH}}$$

$$\text{Pot } R_3 = \frac{10 \times .284}{10} = .284$$

$$\text{Pot } R_4 = \frac{10 \times .0111}{10} = .0111$$

Solving for the second term

$$\eta_{DH} = \frac{\eta_R (.026)}{1 + 50S}$$

$$\text{or } \dot{\eta}_{DH} = \frac{.026 \eta_R - \eta_{DH}}{50}$$

$$\text{or } \dot{\eta}_{DH} = .0005 \eta_R - .02 \eta_{DH}$$

$$\text{Pot } R_5 = \frac{10 \times .02}{10} = .02$$

$$\text{Pot } R_6 = \frac{10}{10} \times .0005 = .0005 \text{ but since this is so small it is divided}$$

between Pots R6 and R7

$$\text{Pot } R_6 = .02 \text{ and Pot } R_7 = .025$$

The schematic for η_{Total} is the sum of the two terms.

10. Basic Definition

$$M = \frac{1}{\eta} \frac{dn}{dt}$$

Where M = inverse period

η = % of power level

And then again by integration:

$$\int M dt = \ln \eta$$

$$11. \quad 5 \log_{10} \eta = 2.17 \int M dt = 2.17 \ln \eta_m$$

$$\text{Defined: } \ln \eta = \int M dt$$

$$\text{But } \ln \eta = \ln 10 \log_{10} \eta$$

$$\text{Or } \ln \eta = 2.3 \log_{10} \eta$$

$$\text{Or } 2.3 \log_{10} \eta = \int M dt$$

$$\text{Or } 5 \log_{10} \eta = 2.17 \int M dt = 2.17 \ln \eta_m$$

(See AGC Drawing 1114313, Sheet 8)

$$\text{Pot R1} = 2.17/.347 = 6.25$$

$$12. \quad .347 \int M dt = (.8 \ln \eta_m)/\ln 10 = .347 \ln \eta_m$$

(See AGC Drawing 1114313, Sheet 8)

$$\text{Gain Pot R3} = 1 \times .347 = .347$$

$$13. \quad W_n = \frac{8.17 P_8}{\sqrt{T_8}}$$

(See AGC Drawing 1114313, Sheet 10)

$$\sqrt{\frac{T_8}{500}} = \sqrt{\frac{10}{500}} \times \sqrt{T_8} = 3.13/22.3 \times \sqrt{T_8} = .1413 \sqrt{T_8}$$

$$\text{Then } \frac{(P_8/100)}{.1413 \sqrt{T_8}} \times 10 = P_8/1.413 \sqrt{T_8} = .71 \frac{P_8}{\sqrt{T_8}} = \frac{.71}{8.17} W_n = \frac{W_n}{11.5}$$

$$14. \quad \rho_8 = .0575 \int (\dot{W}_c - 1.017 \dot{W}_n) dt$$

(See AGC Drawing 1114313, Sheet 10)

$$\text{Gain Pot R3} = \frac{11.5 (.0575)(1.017)}{4 \times 10^{-3}} = 169$$

$$\text{Gain Pot R2} = \frac{10 \times .0575}{4 \times 10^{-3}} = 144$$

$$15. \quad P_8 = 767/144 \rho_8 T_8 = 5.32 \rho_8 T_8$$

(See AGC Drawing 1114313, Sheet 10)

$$\frac{A \rho_8}{4 \times 10^{-3}} \times \frac{T_8}{500} \times \frac{1}{10} = \frac{A \rho_8 T_8}{20} = 5.32 \rho_8 T_8 \text{ When } A = 106.4$$

But since we are producing $P_8/100$ instead of P_8 ,

$$\text{Gain Pot R1} = 106.4/100 = 1.064$$

$$16. \quad W_c^2 = 43.67 (P_6 - P_8)$$

(See AGC Drawing 1114313, Sheet 10)

$$\text{Gain Pot R5} = \frac{100 \times 43.67}{1000} = 4.367$$

$$\text{Gain Pot R3} = \frac{100 \times 43.67}{1000} = 4.367$$

$$17. \quad P_6 = 26.6 \int (W_p - 1.056 W_c) dt$$

(See AGC Drawing 1114313, Sheet 10)

$$\text{Gain Pot R8} = \frac{26.6 \times 10}{100} = 2.66$$

$$\text{Gain Pot R6} = \frac{26.6 \times 1.056 \times 10}{100} = .2.81$$

$$\text{Gain Pot R7} = 14.7/(100 \times 10) = .0147$$

$$18. \quad W_p^2 = 21.98 (P_3 - P_6)$$

(See AGC Drawing 1114313, Sheet (10))

$$\text{Gain Pot R5} = \frac{21.98 \times 100}{1000} = 2.198$$

$$\text{Gain Pot R6} = \frac{21.98 \times 100}{1000} = 2.198$$

$$19. \quad T_3 = T_2 + 1.84 \times 10^{-8} N^2 + 4.31 \times 10^{-6} \dot{W}_P N - 6.82 \times 10^{-4} (\dot{W}_P)^2$$

(See AGC Drawing 1114313, Sheet 10)

$$\text{Gain Pot R2} = \frac{T_2}{(10)(56)} = 36.5/560 = .065$$

$$\text{Gain Pot R5} = \frac{1.84 \times 10^{-8} \times 6.25 \times 10^{-7}}{(56)} = .0205$$

$$\text{Gain Pot R4} = \frac{4.31 \times 10}{4 \times 10^{-6} (56)} = .0192$$

$$\text{Gain Pot R3} = \frac{6.82 \times 10^{-4} \times 1000}{56} = .0122$$

$$20. \quad P_3 = P_2 + 1.5 \times 10^{-6} N^2 + 3.5 \times 10^{-4} W_P N - 5.56 \times 10^{-2} (W_P)^2$$

(See AGC Drawing 1114313, Sheet 9)

$$\text{Gain Pot R4} = \frac{36}{(100)(10)} = .036$$

$$\text{Gain Pot R3} = \frac{1.5 \times 10^{-6} \times 6.25 \times 10^7}{100} = .9375$$

$$\text{Gain Pot R2} = \frac{(3.5 \times 10^{-4})}{4 \times 10^{-6} \times (100)} = .8750$$

$$\text{Gain Pot R1} = \frac{5.56 \times 10^{-2} \times 1000}{100} = .5560$$

$$21. \quad M_P = 76/21,000 \quad (9.07 \times 10^{-4} \quad N^2 - .0667 \quad N \dot{W}_P + 15.95 \dot{W}_P^2)$$

$$\text{Gain Pot R1} = \frac{.0667 \times 76}{.021,000 \times 200 \times 4} = .3000$$

$$\text{Gain Pot R2} = \frac{15.95 \times 76 \times 1000}{21,000 \times 200} = .2900$$

$$\text{Gain Pot R3} = \frac{9.07 \times 10^{-4} \times 76 \times 6.25 \times 10^7}{21,000 \times 200} = 1.03$$

$$22. \quad \dot{N} = 89 \quad M_T - 75 \quad M_P$$

(See AGC Drawing 1114313, Sheet 11)

$$\text{Gain Pot R4} = 75/2500 \times 200 = 6.00$$

$$\text{Gain Pot R5} = 89/2500 \times 333 = 11.8$$

$$23. \quad M_T = 3.47 \quad P_{15}$$

(See AGC Drawing 1114313, Sheet 11)

$$10.4 \quad P_{15}/P_8 \times P_8/100 \times 1/10.0 = .0104 \quad P_{15}$$

$$\text{Since } M_T = 3.47 \quad P_{15} \text{ and Output} = .0104 \quad P_{15}$$

$$\text{Then Output} = M_T/333$$

$$24. \quad P_{15}/P_8 = f \quad (\Theta_{\text{TPCV}})$$

$$25. \quad H_R = 109 \quad n - 51.2 \quad (\dot{W}_P) \left(\phi_R - \frac{T_5 + T_6}{2} \right)$$

(See AGC Drawing 1114313, Sheet 4)

$$\text{Pot R3} = \frac{1000 \times 51.2}{25,000} = 2.05$$

$$\text{Pot R4} = \frac{190 \times 10}{25,000} \times \frac{10}{10.7} = .070 \quad \text{Where } \eta \text{ is scaled to } 10\text{V} = 100\% \text{ power.}$$

$$26. \quad \phi_R = f(H_R)$$

$$27. \quad T_5 = T_3 + .0222 T_8$$

(See AGC Drawing 1114313, Sheet 4)

$$\text{Pot R1} = \frac{.0222 \times 500}{100} = .1110$$

$$\text{Pot R2} = 56/100 = .560$$

$$28. \quad T_6 = T_5 + 14 \left[\phi_R - \frac{T_5 + T_6}{2} \right]$$

(See AGC Drawing 1114313, Sheet 4)

$$\text{Gain Pot R5} = \frac{14 \times 10}{100} = 1.40$$

$$\text{Gain Pot R6} = 100/100 = 1.000$$

$$29. \quad \dot{H}_c = 10,800 \eta - 44 \dot{W}_c \left[\phi_c - \frac{T_6 + T_8}{2} \right]$$

(See AGC Drawing 1114313, Sheet 13)

$$\text{Pot R4} = \frac{10,800 \times 10}{600,000} \times \frac{10}{10.7} = .169$$

$$\text{Pot R3} = \frac{44 \times 10,000}{600,000} = .735$$

$$30. \quad \phi_c = f(H_c)$$

$$31. \quad T_8 = T_6 + 11.6 \left[\phi_c - \frac{T_6 + T_8}{2} \right]$$

(See AGC Drawing 1114313, Sheet 13)

$$\text{Gain Pot R5} = 100/500 = .200$$

$$\text{Gain Pot R6} = \frac{100 \times 11.6}{500} = 2.33$$

$$32. \quad T_{tr} = 7.87 T_6 - 0.31 \phi_{SG} \quad \text{See AGC Drawing 1114313, Sheet 13}$$

$$33. \quad \text{Pot R6} = \frac{500 \times .31}{200} = .770$$

$$\text{Pot R7} = \frac{100 \times 7.87}{200} = 3.94$$

$$34. \quad \text{Station 26} = T_8 - 400^\circ\text{R}$$

$$\text{Pot A} = 500/500 = 1.00$$

$$\text{Pot B} = 400/(10 \times 500) = .080$$

$$35. \quad \text{Station 20} = .770 (ST_{26} - T_6) + T_6$$

$$\text{Pot A} = (.770 \times 500)/500 = .770$$

$$\text{Pot B} = 100/500 = .200$$

COOLDOWN EQUATIONS FOR GHe

$$36 \text{ and } 37. \quad W_n = 20 P_8 / \sqrt{T_8} \quad \text{Versus} \quad W_n = 8.17 P_8 / \sqrt{T_8}$$

Going back to the solution of Equation 17 in making up W_n

$$\frac{P_8/100 \times 10}{.1413 \sqrt{T_8}} = .71 P_8 / \sqrt{T_8} = .71/20 \quad W_n = W_n/27.8 \text{ instead of } W_n/11.5$$

Therefore in making $+ \rho_8/(4 \times 10^{-3})$ in the equation

$$\rho_8 = .0288 \int (W_c - 1.017 W_n) dt$$

$$\text{Pot A} = \frac{27.8 \times 1.017 \times .0288}{4 \times 10^{-3}} = 203$$

$$\text{Pot B} = \frac{10 (.0288)}{4 \times 10^{-3}} = 72$$

$$38. \quad P_6 = 13.3 \int (W_p - 1.056 W_c) dt$$

$$\text{Pot A} = \frac{13.3 \times 1.056 \times 10}{100} = 1.41$$

$$\text{Pot B} = \frac{13.3 \times 10}{10} = 1.33$$

$$39. \quad P_8 = 2.67 \rho_8 T_8$$

$$\frac{A \rho_8}{4 \times 10^{-3}} \times \frac{T_8}{500} \times \frac{1}{10} = \frac{A \rho_8 T_8}{20} = 2.67 \rho_8 T_8 \text{ or } A = 53.4$$

But since we are producing $\frac{P_8}{100}$ instead of P_8

$$\therefore \text{Pot A} = \frac{53.4}{100} = .534$$

3.2 TSS COOLDOWN

3.2.1 TSS Cooldown Description

3.2.1.1 Introduction

The intent of this cooldown simulation section is to describe the following information concerning the cooldown simulation:

- (a) Physically located equipment
- (b) Schematically identify equipment
- (c) Describe peculiar setup procedures and operational checks
- (d) Define equations used for the simulation
- (e) Note applicable reference drawings

Eleven functional groups containing fourteen subgroups that share some common components, thus making it the equivalent of nineteen separate groups, make up the ETS-1 cooldown simulation and are interconnected through the analog patch board. This simulation has 220 describing electrical equations which are similar in form to the 150 describing physical equations of the ETS-1 four-fluid, cooldown facility.

The cooldown subsystem simulates a gaseous/liquid fluid system consisting of (1) LH_2 , (2) GH_2 , (3) GHe and (4) LN_2 ; each having at least one analog control valve (PCV) and independent source.

The manner in which these functional groups operate is controlled through the digital logic chassis which in turn is connected to each functional group through the logic patch board. Both the analog and logic patch boards provide the means so each functional group can be isolated and independently operated. This feature provides a valuable tool during the de-bugging and trouble shooting operations.

The eleven functional groups are contained in racks 58A, 58B, 59A, 59B, 60A and 61B as shown in Figures 14 and 15.

The following drawings shall be referred to when investigating the setup procedures:

- (a) AGC Drawing 1114289
- (b) EA1 Drawing 00402300A
- (c) EA1 Drawing 00402290A
- (d) EA1 Drawing 0040280A
- (e) EA1 Drawing 00402270A

It should be noted that there are a few spare parts scattered throughout the hardware layout. These spares are identified on AGC Drawing 1114289.

3.2.1.2 Fluid Sources

The significant differences in simulation between the four fluid sources (two gaseous, two liquid) are as follows: (1) the GHe source is simulated as a finite source with isentropic blowdown, thus pressure and temperature of the GHe source are variables; (2) the GH_2 source is scaled as an infinite source having constant source pressure and temperature but is treated in computer circuitry as a variable; (3) the LH_2 and (4) LN_2 sources are also simulated as being constant infinite sources.

3.2.1.3 Facility Manifolds

There are two major manifolds in the cooldown subsystem: (1) Gas manifold, where GH_2 and GHe are serialized; and (2) the common manifold, where LH_2 and LN_2 and one where the previously serialized gaseous coolants are serialized. (Reference AGC Drawing 1114329.) The simulation of the interaction between the fluid in these manifolds utilizes only pressure coupling; no mixing equations or interfluid heat transfer effects are simulated.

Figure 14 - Cooldown Simulator: Front View

Figure 15 - Cooldown Simulator: Rear View

3.2.1.4 Component Sharing

Sharing of nonlinear analog components (multipliers, squarers, square rooters, dividers) and algebraic simmers between fluids having similar circuit configurations and asymmetrical modes is utilized. The permissive feature of the cooldown simulation sharing technique is the premise that only one fluid would be commanded to flow at any given time (asymmetrical modes). Simulation circuits of parameters such as pressures and temperatures that are non-zero continuous partial functions of time are not shared, i.e., discrete unshared circuits are used for these.

3.2.1.5 Interscaling Ratios

Interfluid and simulation intersystem (TSS cooldown to TSS engine and control systems to TSS) scaling ratios are utilized to enable higher accuracy simulation computation and still retain electrical and loop compatibility with peripheral systems. Interfluid scaling ratios can be observed in each of the two manifolds, where tracking and initial condition insertion are used to maintain lower order subsystem scaling integrity and sharing capacity.

3.2.1.6 TSS Logic Network

The logic network of the TSS (reference EAI Drawing 04.00551) is essentially used in conjunction with the cooldown subsystem of TSS. The logic system has various uses: (1) Analog to digital conversion; (2) sharing mode "switch"; (3) isolation and computer mode control for trouble shooting; and (4) translation between Process System Control and computer circuitry of TSS.

3.2.1.7 Computation Datum

The initiation of the datum or starting mode for the TSS is another major use of the logic block of the TSS. The control switches for the datum mode is entitled "RESET" and located on Rack 60 and Rack 01L on the "TSCS SIMULATION PANEL." The RESET mode has the following effects on the cooldown block: (1) Resets the GHe source to the 100% pressure, weight, and ambient temperature conditions; (2) vents all cooldown pressures to ambient; (3) resets all cooldown temperatures to ambient; and (4) restricts all cooldown weight flows to zero. From the Reset mode the cooldown simulation is subordinated to the valve commands from the process system control consoles via the TSS logic network. The logic selects the proper fluid computation share relays and constructs the computer model for the specific fluid and the computation becomes a function of conditions such as PCV command amplitude and engine nozzle "BACK" or "LOAD" pressure, P_{e_3} .

3.2.1.8 The various transducers shown on AGC Drawing 1114329, which represent flow, pressure, valve step position (or angle), and temperature are scaled to the most recent facility transducer volts per measured unit in magnitude only. No time constants of lag are scaled for the general transducer. (Reference Table

3.2.1.9 Transient Versus Steady-State Scaling

The cooldown simulation of the TSS is generally scaled to the maximum steady-state physical magnitude and all discrete functions of time are scaled in real time ($\tau = t = 1$). Many of the amplifiers that simulate variables that have excessively high transients are zener-diode limited in such a compromising manner that the steady-state magnitude is accurate, and the essential transient effects are maintained.

TABLE 8
TRANSDUCER SCALING

<u>TSS</u> <u>SYMBOL</u>	<u>FUNCTION</u>	<u>FUNCTIONAL</u> <u>GROUP</u>	<u>PSC AND</u> <u>FACILITY</u> <u>SCALING</u>	<u>MACHINE</u> <u>SCALING</u>	<u>PSC</u> <u>SCALING</u>
$\dot{W}_{11}/2$	FT12	LH ₂	0-10V 0-50 lb/sec	0-10V 0-50 lb/sec	Same
$P_{10}/2$	PT101	LH ₂	0-5V 0-1500 psig	Same	0-3.24V 0-1000 psia
$P_{15}/2$	PT484	LH ₂	0-5V 0-1500 psig	Same	0-3.24V 0-1000 psia
$T_4/2$	TT28	Control and Feed	0-5V 35°-610°R	0-5V 35-610°R	Same as New Mach Scaling
$T_4/2$	TT495	Control and Feed	0-5V 35°-60°R	0-5V 35-60°R	Same as New Mach Scaling
$L_{472}/2$	PCV472 Pos.	LH ₂	0-5V 0-100%	Same	Same
$\dot{W}_2/2$	FE52	LN ₂	0-5V 0-40 lb/sec	Same	0-5V 0-40 lb/sec
$P_2/2$	PT194	Control and Feed	0-5V 0-300 psig	Same	0-250 psia
$T_1/2$	TT55	Control and Feed	0-5V 130°-610°R	0-5V 135-610°R	Same as New Mach. Scaling
$L_{517}/2$	PCV517 Pos.	LN ₂	0-5V 0-100%	Same	Same
$\dot{W}_4$	FT415	GHe	0-10V 0-50 lb/sec	Same	Same
$P_6/2$	PT473	GHe	0-5V 0-2500 psig	Same	0-5V 0-2500 psia
	TT45	Control and Feed	0-5V 360°-560°R		
$L_{471}/2$	PCV471 Pos.	GHe	0-5V 0-100%	Same	Same

TABLE 8 (cont.)

<u>TSS SYMBOL</u>	<u>FUNCTION</u>	<u>FUNCTIONAL GROUP</u>	<u>PSC AND FACILITY SCALING</u>	<u>MACHINE SCALING</u>	<u>PSC SCALING</u>
$\dot{W}_8$	FT15	GH ₂	0-10V 0-40 lb/sec	Same	0-10V 0-40 lb/sec
P_{14}	PT475	Control and Feed	0-5V 0-1000 psig	Same	0-5V 0-1000 psig
$L_{251}/2$	PCV251 Pos.	GH ₂	0-5V 0-100%	Same	Same
P_{13}	PT103	Common Manifold	0-5 = 0-300	Same	0-5V 0-300 psig
P_{13}	PT891	Common Manifold		Same	0-5V 0-1000 psia
	TT474	Common Manifold			0-5V 35°-610°R
	TT496	Common Manifold			0-5V 35°-60°R
	TT881	Common Manifold			0-5V 35°-610°R

3.2.2 TSS Cooldown Theory of Simulation

3.2.2.1 Pressure Control Valves

3.2.2.1.1 General Flow Equation

The general flow equation for any valve:

$$\dot{W} = C_1 A_e (2g \rho_m \Delta P)^{1/2}$$

3.2.2.1.2 Sonic Flow

$$\rho_1 = \frac{P_1}{RT_1}$$

Where P_1 = Upstream Pressure

$$\dot{W} = C_1 A_e \sqrt{2g/R} \frac{P_1}{\sqrt{T_1}} = f \text{ (Upstream Conditions)}$$

3.2.2.1.3 Subsonic Flow

$$\dot{W} = C_2 A_e (\Delta P)^{1/2} = f \text{ (Upstream and Downstream Conditions)}$$

Since the gaseous PCV(s) must control flow ranging over $0 \leq W \leq W_{\text{Sonic}}$, the simulation must either contain dual simulation with switching between the two simulated equations @ $\Delta P = \Delta P_{\text{Critical}}$, or some other general approximate equation must be provided. An equation utilizing Smith's Constant, K_S , is a possible single equation solution to this sonic/subsonic wide flow simulation of gases.

3.2.2.2 GENERALIZED FLOW EQUATION FOR SONIC AND SUBSONIC FLOW OF A GAS THROUGH A VALVE

$$\dot{W} = \frac{K_S A_e P_o N_S}{\sqrt{T_o}}$$

Where:

P_o = Total Upstream Pressure (psia)

= Vel Head + Static Head

A_e = Effective Valve Area $\perp$ to Flow ($1N^2$)

K_S $\equiv$ Smith's Constant

$$\equiv \sqrt{\frac{\kappa g}{R}} \left[1 + \frac{\kappa - 1}{2} \right] - \left[\frac{\kappa + 1}{2(\kappa - 1)} \right]$$

3.2.2.2.1 Sonic/Subsonic Normalizing Factor- N_S

$$N_S \equiv \sqrt{\frac{\kappa g}{R}} \frac{\left\{ \left(\frac{2}{\kappa - 1} \right) \left[\left(\frac{P_o}{P_{DS}} \right)^{\left(\frac{\kappa - 1}{\kappa} \right)} - 1 \right] \right\}^{1/2}}{\left(\frac{P_o}{P_{DS}} \right)^{\left(\frac{\kappa - 1}{2\kappa} \right)}} \cdot \left[\frac{1}{\kappa_S} \right]$$

T_o = Total Temperature

P_{DS} = Downstream Pressure f Valve

κ = $\begin{cases} 1.4 & \text{for } GH_2 \end{cases}$

= $\begin{cases} 1.67 & \text{for } GHe \end{cases}$

R = $\begin{cases} 766.53 \text{ ft}/^\circ R & \text{for } GH_2 \end{cases}$

= $\begin{cases} 386.33 \text{ ft}/^\circ R & \text{for } GHe \end{cases}$

It can be shown that the factor

$$N_S = f \left(\frac{P_o - P_1}{P_o} \right) \text{ and has a maximum value of 1 near the point}$$

$$\text{where } \Delta P/P_o = 1/2$$

3.2.2.2.2 Smith's Constants, K_S

$$K_{S \text{ GH}_2} = 0.1402 \sqrt{^\circ R/\text{sec}}$$

$$K_{S \text{ GHe}} = 0.323 \sqrt{^\circ R/\text{sec.}}$$

3.2.2.3 General Gas Flow Equations for GH_2 and GHe

3.2.2.3.1 GH_2

$$\dot{W} = 0.1402 A_e N_{S_{\text{GH}_2}} P_{\text{upstream}} / \sqrt{T}$$

3.2.2.3.2 GHe

$$\dot{W} = 0.323 A_e N_{S_{\text{GHe}}} P_{\text{upstream}} / \sqrt{T}$$

3.2.2.3.3 Gas Flow Approximation

Noting the shape of $N_S = f(\Delta P/P)$: The very high gain (slope) of the curve near $(\Delta P/P) = 0^+$ is difficult to simulate on a function generator of an analog computer. This limitation leads to an approximation of general gas flow equations through variable orifices.

Given: $\dot{W}_{\text{gas}} = K_S \frac{A_e}{\sqrt{T_1}} P_1 N_S$

Assume: $P_1 N_S = 2 \sqrt{P_2 (P_1 - P_2)}$

Where:

P_1 = Upstream Pressure

P_2 = Downstream Pressure

And check numerically

It can be shown that for $0 \leq N_S \leq 1$ that the above assumption is accurate within $\pm 2.5\%$. This is sufficient accuracy for the TSS.

Therefore:

$$\dot{W}_{\text{gas}} = K_S \frac{A_e}{\sqrt{T}} 2 \sqrt{P_2 (P_1 - P_2)}$$

Where: $P_1 < R_{\text{Crit}} P_2$

and

$$\dot{W}_{\text{gas}} = K_S \frac{A_e}{\sqrt{T}} P_1$$

Where: $P_1 \geq R_{\text{Crit}} P_2$

R_{Crit} = Critical Pressure Ratio

3.2.2.4 LIQUID FLOW:

Since the flow of liquids through valves is necessarily restricted to and assumed to always be subsonic, the weight flow equations are simplified in comparison to the gaseous flow equations. Referring to Page 1, there are two equations required to relate the parameters; for the liquid case, only the subsonic equation is necessary.

Thus

$$\dot{W} = C_2 A_e (\Delta P)^{\frac{1}{2}} = C_2 A_e (P_o - P_1)^{\frac{1}{2}}$$

But since most valve data or specifications rate value in terms of a flow coefficient, C_v ; we need to relate C_v to A_e . This can be shown to be:

$$A_e \propto C_v \quad \text{OR} \quad A_e = C_3 C_v$$

Thus for the liquids:

$$\dot{W} = C_2 C_3 C_v (P_o - P_1)^{\frac{1}{2}} \quad \text{or}$$

$$\dot{W} = C_4 C_v (P_o - P_1)^{\frac{1}{2}}$$

where

C_v = Flow Coefficient (Gal/Min)

P_o = Total Upstream Pressure (PSIA)

P_1 = Total Downstream Pressure (PSIA)

$C_4 = C_2 C_3$ = Product of Proportionality Constants

3.2.2.5 VALVE FLOW COEFFICIENT, C_v :

Referring to the Hydraulic Equation -

$$Q = C_1 A_e (2g \rho_f^{-1} \Delta P)^{\frac{1}{2}} \quad \text{where}$$

$$C_1 = \text{Constant (GPM) - sec/in.}^3$$

$$\Delta P = \text{Differential Pressure (PSIA)}$$

$$Q = \text{Volumetric Flow Rate (GPM)}$$

$$\rho_f = \text{Fluid Weight Density (lb/in.}^3)$$

$$g = \text{Acceleration Due to Gravity} = 386 \text{ in./sec}^2$$

and substituting -

$$Q = \frac{1 \text{ GPM}}{231 \text{ in.}^3 / \frac{\text{min}}{60}} \times A_e \text{ in.}^2 \left(\frac{2 \times 386 \text{ in./sec}^2 \times \Delta P \text{ PSI}}{62.4 \text{ lb/1728 in.}^3} \right)^{\frac{1}{2}}$$

$$Q = 37.98 A_e \sqrt{\Delta P} \quad (\text{GPM})$$

$$\text{by definition of } C_v \quad Q = C_v \text{ AT } \Delta P = 1$$

$$\text{thus - } A_e = \frac{C_v}{37.98} \text{ in.}^2$$

$$A_e = 2.64 \times 10^{-2} C_v \text{ in.}^2$$

In Report #65-6 of the Equipment Testing Laboratory of Los Alamos Scientific Laboratory, it was shown that the C_v rating as given by most valve manufacturers is too conservative, i.e., the maximum flow of a given valve is greater by an amount sufficient to yield significant inaccuracies in TSS design, should the manufacturer's C_v value be used. Report #65-6 recommends an empirically derived relationship of:

$$\begin{array}{l} A_e = \frac{C_v}{20} \text{ in.}^2 \\ \boxed{A_e = .05 C_v \text{ in.}^2} \end{array} \left\{ \begin{array}{l} \text{where - the } C_v \text{ shown is the manufacturers' } \\ C_v. \text{ The small divisor tends to} \\ \text{correct conservatism.} \end{array} \right.$$

This latter relationship will be used and a tabulation of the effective areas, A_e of the valves used in cooldown are shown in Table 9. Note that the constant 37.98 as derived from the hydraulic equation is not in significant error, only the C_v is too small.

TABLE 9 COOLDOWN VALVES - AREA
(EFFECTIVE - PLUG TYPE)

VALVE DESIGNATION	C_V (GPM) (MANUFACTURER)	EFFECTIVE AREA (IN ²)		PLUG TYPE
		$A_e = C_V/20$	$A_e = C_V/37.98$	
50PCV517	125	6.25	3.30	50:1
50PCV251	190	9.50	5.02	50:1
50PCV449	1800	90.00	47.50	50:1
50PCV472	130	6.50	3.43	50:1
50RSV78	580	29.00	15.31	SEMI-THROTTLE
50RSV201	580	29.00	15.31	
50RSV454	680	34.00	17.95	
50RSV460	680	34.00	17.95	
50RSV458	625	31.22	16.50	
50RSV459	625	31.22	16.50	
50RSV545	625	31.22	16.50	
50RSV107	580	29.00	15.30	Butterfly
CSV	890	44.50	23.50	

3.2.2.6 Valve Actuators

3.2.2.6.1 General

Consideration of the valve data which is available from vendor and that data which is relatively easy to obtain by simple valve tests, plus a consideration of what minimum amount of data would most characteristically simulate the essential parameters of given valves led to the methods of simulation which follow:

3.2.2.6.2 Electro-Pneumatic PCV:

$$\frac{\text{Lift (in)}}{\text{Voltage (Command) (Volt)}} (s) = \frac{K_1}{(1 + \gamma_1 S)(1 + \tau_2 S)}$$

$$\text{where } K_1 = \frac{\text{Max Lift (in.)}}{\text{Max Vc (Volts)}}$$

This equation is that of a second order lag; but which allows easy insertion of velocity limits both opening and closing, lift or stroke limits, and is dependable and repetitive stability-wise. The velocity and lift limits are considered as essential characteristics and are easily available both from vendor and by simple testing. The time constants, τ_1 and τ_2 , are available from vendor, or may be determined by frequency tests.

3.2.2.6.3 Electro-Pneumatic RSV

Considering that the most essential parameters that define the characteristics of a two-state valve actuator like an RSV are both velocity limits (opening and closing) and the position or lift limits of the valve stem plus the fact that the most available data from vendor or from

simple testing are these velocity and position limits, led to the choice of a second order lag simulation of an RSV actuator as below:

$$\frac{\text{Lift (in)}}{\text{Voltage (Command) (Volts)}} (s) = \frac{K_3}{(1 + \tau_5 s)(1 + \tau_6 s)}$$

where

$$K_3 = \frac{\text{Max Lift (in.)}}{\text{Max Voltage Command (Volts)}}$$

3.2.2.7 LINE LUMPS - Each line lump typically contains a compliance, an inertance, and a resistance. (NOTE: There are exceptions in TSS where a lump may be only a compliance.)

3.2.2.7.1 Typical Line Lump Equations

$$\dot{W}_1 = \frac{A_1 g}{\ell_1} \int (P_1 - K_R \dot{W}_1^2 - P_2) dt \quad \text{where:}$$

A_1 = Area of Lump

ℓ_1 = Length of Lump

$$P_2 = \frac{\beta}{\kappa \rho g} \frac{1}{A_1 \ell_1} \int (\dot{W}_1 - \dot{W}_2) dt + P_2(o)$$

3.2.2.7.2 Line Impedances

From equations of 3.2.2.7.1 the lump impedances become

$$3.2.2.7.2.1 \text{ Fluid Compliance} = C = \kappa A_1 \ell_1 \frac{\rho}{\beta}$$

$$3.2.2.7.2.2 \text{ Fluid Inertance} = L = \frac{\ell_1}{A_1 g}$$

$$3.2.2.7.2.3 \text{ Fluid Resistance} = f(\dot{W}) = (K_R \dot{W})$$

3.2.2.7.3 Pressure Drops

Then the respective pressure drops due to each fluid impedance component becomes:

$$\Delta P | = K_R \dot{W}^2$$

$$\frac{\dot{\Delta} P}{\Delta P} | = \frac{\beta}{\rho_f} \frac{1}{Vol} (\dot{W}_{in} - \dot{W}_{out}), Vol = A_1 \ell_1$$

$$\Delta P | = \frac{1}{A_1 g} \frac{d}{dt} \cdot \dot{W}$$

3.2.2.7.4 Typical Line (GH₂) Computation

Lump 1

50 PCV 251

502.34'

$$A = 0.181 \text{ ft}^2, \text{ Vol} = 141.06 \text{ ft}^3, \angle 90^\circ = 14, T = 4, V = 2$$

For gaseous GH₂ @ 560°R, 2500 psia, $\rho_f = 0.9$

$$v = 14.6 \times 10^{-6} \text{ ft}^2/\text{sec}, \dot{w}_{\max} = 50 \text{ lb/sec}$$

$$N_{\text{Re}} = \frac{\dot{dw}}{v \rho_f A} \quad \text{for Lump 1 GH}_e \text{ manifold to 50 PCV 449}$$

$$\text{Pipe ID} = 0.432 \text{ ft}, A = 0.147 \text{ ft}^2, E/d = 0.0004$$

$$l = 502.34 \text{ ft}$$

Substitute
then

$$N_{\text{Re}} = \frac{0.432 \text{ ft} \times 50 \text{ lb/sec}}{14.6 \times 10^{-6} \text{ ft}^2/\text{sec} \times 0.9 \text{ lb/ft}^3 \times 0.147 \text{ ft}^2} = 11.2 \times 10^{-6}$$

$$\therefore f = 0.016$$

Lump Model

$$\Delta P \mid \text{---} = K_R \dot{w}_1^2$$

$$\dot{w}_1 = \frac{A_1 g}{l_1} \int (P_1 - K_R \dot{w}_1^2 - P_2) dt$$

$$\Delta P \mid \text{---} = \frac{\beta}{\rho} \frac{1}{A_1 l_1} (\dot{w}_{\text{in}} - \dot{w}_{\text{out}})$$

$$P_2 = \frac{\beta}{K \rho_g} \frac{1}{A_1 l_1} \int (\dot{w}_1 - \dot{w}_2) dt + P_2(o)$$

$$\Delta P \mid \text{---} = \frac{l_1}{A_1 g} \frac{d}{dt} \dot{w}$$

$$\text{Fluid Compliance} = C = \frac{K A \ell_1 \rho_g}{\beta}$$

$$\text{Fluid Inertia} = L = \frac{\ell_1}{A_1 g}$$

$$\text{Fluid Resistance} = f(\dot{w}) = K_R \dot{w}^2$$

$$\Delta P \mid = f \left(\frac{\ell}{d} \right) \frac{\dot{w}_1}{2 \rho_f A_g^2} = K'_{R34} \dot{w}_1^2$$

$$\begin{aligned} \therefore K'_{R34} &= f \left(\frac{\ell}{d} \right) \frac{1}{2 \rho_f A_g^2} \\ &= 14.85 \frac{\text{sec}^2}{\text{lb ft}^2} \\ &= 14.85 \frac{\text{sec}^2}{\text{lb ft}^2} \cdot \frac{\text{ft}^2}{144 \text{ in}^2} \\ &= 0.103 \frac{\text{sec}^2}{\text{lb in.}^2} \end{aligned}$$

In Lump 1, the ΔP due to fittings:

$$K_{f34} = \frac{\Sigma K_{f1}}{2 \rho_g A^2} = \frac{\Sigma K_{f1}}{(2)(.9)(32.2)(.147)^2} = 0.8 \Sigma K_{f1} \frac{\text{sec}^2}{\text{lb ft}^2}$$

In Lump 1 there are 14 - $\angle 90$, 4 - Tees, 2 - v

$$\begin{aligned} \therefore \Sigma K_{fi} &= 14(0.67) + 4(1.75) + 2(0.25) \\ &= 9.39 + 7 + 0.5 \\ &= 16.89 \frac{\text{sec}^2}{\text{lb in.}^2} \end{aligned}$$

Thus

$$K_{f34} = (0.8)(16.89) \left(\frac{1}{144} \right) = 0.0939 \frac{\text{sec}^2}{\text{lb in}^2}$$

And

$$K_{R34} = K'_{R34} + K_{f34} = 0.103 + 0.0939$$

$$K_{R34} = 0.1969 \frac{\text{sec}^2}{\text{lb in}^2}$$

Lump 2

$$\begin{aligned} & 25' \\ A &= 0.181 \text{ ft}^2 \\ \text{Vol} &= 5 \text{ ft}^3 \end{aligned}$$

Lump 2 has only compliance,
Resistance is incorporated into
Lump 3

Lump 3

$$16 \quad K_{R39}$$

$$\ell = 16' \quad V = 6.25, A = 0.181$$

$$\angle 90 = 3 \quad T = 6, \text{CHV} = 1, V = 2$$

$$K_{R39} = K'_{R39} + K_{F39}$$

NR_e is same as lump 1

$$\therefore f = 0.016$$

$$\Delta P / \quad = \quad f \frac{\ell}{d} \quad \frac{\dot{w}^2}{2\rho A^2 g} = K' \dot{w}^2$$

$$K'_{R39} = \frac{(1.6 \times 10^2) (25 + 16)}{(2)(0.9)(32.2)(.147)^2 (144)(.432)} \quad \frac{\text{sec}^2}{\text{lb in}^2}$$

$$= 0.844 \quad \frac{\text{sec}^2}{\text{lb in}^2}$$

$$K_{F39} = \frac{\Sigma K_{f3}}{2\rho_f gA^2} \approx 0.80 \Sigma K_{f3}$$

In lumps 2&3 there are: 3- $\angle 90^\circ$, 6-T, ICHV, 2-V

$$\therefore \Sigma K_{f3} = 3(0.67) + 6(1.75) + 1(3.0) + 2(0.25)$$

$$= 2.01 + 10.5 + 3 + .5 \approx 16 \quad \frac{\text{sec}^2}{\text{lb ft}^2}$$

$$\therefore K_{F39} = 0.80 \Sigma K_{f3} = (0.8) \left(\frac{16}{144}\right) = 0.0889 \quad \frac{\text{sec}^2}{\text{lb in}^2}$$

$$\therefore K_{R39} = K'_{R39} + K_{F39} = 0.844 + 0.0889$$

$$K_{R39} = 0.9329 \quad \frac{\text{sec}^2}{\text{lb in}^2}$$

Lump 4

CDSV

$$K_{R41}$$

$$L = 102 \text{ ft} = 36 + 66^2 \text{ ft} \quad V = 23.86 \text{ ft}^3$$

$$A = 0.181 \text{ ft}^2 - 0.125 \text{ ft}^2$$

4 - $\angle 90^\circ$, 3-T, 2- $\angle 45^\circ$, 2-CHV, V = 1, 3 = Bellows

For Lump 4

$$KR_{41} = K'_{R41} + K_{F41}$$

$$NR_e = \frac{d \dot{w}}{v \rho_f A}$$

There are two sections of line:

$$(1) \quad 36 \text{ ft}, \quad d_1 = 0.48 \text{ ft}, \quad A_1 = 0.181 \text{ ft}^2$$

$$(2) \quad 66 \text{ ft}, \quad A_2 = 0.125 \text{ ft}^2, \quad d_2 = 0.397 \text{ ft}$$

$$N_{Re} (1) = \frac{(0.48)(50)}{(14.6 \times 10^{-6})(.9)(.181)} = 10.01 \times 10^6$$

$$\therefore f(1) = 0.016$$

$$N_{Re} (2) = \frac{(0.397)(50)}{(14.6 \times 10^{-6})(.9)(.125)} = 12.1 \times 10^6$$

$$\therefore f(2) = 0.016$$

Lump 4

$$\therefore K'_{R41} = f \left(\frac{\ell_1}{d_1 A_1^2} + \frac{\ell_2}{d_2 A_2^2} \right) \frac{1}{2 \rho_f g}$$

$$= \frac{1.6 \times 10^{-2}}{(2)(.9)(3.22 \times 10^{+1})(1.44 \times 10^2)} \left[\frac{36}{(.48)(.181)^2} + \frac{66}{(.397)(.125)^2} \right]$$

$$= 19.15 \times 10^{-7} [2290 + 10650]$$

$$= 1.915 \times 10^{-6} (1.294 \times 10^4)$$

$$= 0.0248 \frac{\text{sec}^2}{\text{lb in}^2}$$

In Lump 4 there are:

4 - $\angle 90^\circ$ (2 in section 1), 3-T (in section 1), 2 - $\angle 45$ (section 1),
2CHV (1 in section 1), 1 - V, 3 - bellows (K - 2.5)

$$K_{F41} = \frac{\Sigma K_{f4}}{2\rho_f g A^2} = \left[\frac{\Sigma K_{f4(1)}}{A_1^2} + \frac{\Sigma K_{f4(2)}}{A_2^2} \right] \frac{1}{2\rho_f g}$$

$$K_{F41} = \frac{1}{(2)(.9)(32.2)} \left[\frac{2(0.67) + 3(1.75) + 2(0.4) + 1(3.0)}{(0.181)^2} + \right.$$

$$\left. \frac{2(0.67) + 1(3.0) + 1(0.25) + 3(2.5)}{(0.125)^2} \right]$$

$$K_{F41} = \frac{1}{(1.8)(32.2)} \left[\frac{10.39}{(0.181)^2} + \frac{12.09}{(0.125)^2} \right] = \frac{317 + 775}{(1.8)(32.2)}$$

$$\therefore K_{F41} = \frac{1092}{(1.8)(32.2)(144)} = 0.131 \frac{\text{sec}^2}{\text{lb in}^2}$$

$$\text{Thus } K_{R41} = K'_{R41} + K_{F41} = 0.0248 + 0.131 = 0.1558 \frac{\text{sec}^2}{\text{lb in}^2}$$

Typical line lump equation

$$\dot{w}_1 = \frac{A_1 g}{\ell_1} \int (P_1 - K_R \dot{w}_1^2 - P_2) dt$$

$$P_2 = \frac{\beta}{k \rho g} \cdot \frac{1}{A_1 \ell} \int (\dot{w}_1 - \dot{w}_2) dt + P_2(\sigma)$$

$$\text{Thus Fluid Compliance} = C = \frac{k A_1 \ell_1 \rho g}{\beta}$$

$$\text{Fluid inertance} = L = \frac{\ell_1}{A_1 g_1}$$

$$\text{Fluid resistance} = K_R \dot{w}$$

$$\Delta P | \text{---} = K_R \dot{w}^2$$

$$\Delta P | \text{---} = \frac{\beta}{\rho_f A_1 \ell} (\dot{w}_1 - \dot{w}_2)$$

$$\Delta P | \text{---} = \frac{\ell_1}{A g} \frac{d \dot{w}}{d t}$$

Gaseous Coolant

$$\frac{\beta}{\rho_f} = \frac{c^2}{g} = \frac{K g R T}{g} \quad \begin{array}{l} K = 1.67 \\ R = 387 \text{ ft}/^\circ\text{R} \end{array}$$

$$\therefore \frac{\beta}{\rho_f} \Big|_{GH_e} = KRT = (1.67) (387 \text{ ft}/^\circ\text{R}) T$$

$$\frac{\beta}{\rho_f} \Big|_{GH_e} = 646 T \text{ ft}/^\circ\text{R}$$

$$P_2 = \frac{\beta}{k\rho A\ell} \int (\dot{w}_1 - \dot{w}_2) dt + P(o)$$

Electrical

$$e_c = \frac{1}{c} \int (i_1 - i_2) dt$$

$$\therefore \text{Fluid compliance} = C = \frac{k\rho A\ell}{\beta}$$

$$\dot{w}_1 = \frac{A_1 g}{\ell} \int (P_1 - K\dot{w}_1^2 - P_2) dt$$

Electrical

$$i_1 = \frac{e_1 - e_2}{R + SL}$$

$$i_1 R + i_1 SL = e_1 - e_2$$

$$i_1 SL = e_1 - e_2 - i_1 R$$

$$i_1 = \frac{1}{SL} (e_1 - e_2 - i_1 R)$$

$$\therefore i_1 = \frac{1}{L} \int (e_1 - e_2 - i_1 R) dt$$

$$\therefore \text{Fluid Inertance} = L = \frac{\ell}{Ag}$$

$$eR = i_1 R$$

$$\therefore \text{Fluid Resistance: } K\dot{w}$$

$$(1) \quad a \quad P_4 = 2500 \text{ psia} \left[1 - 1.128 \times 10^{-4} \int_0^t \dot{W}_4 dt \right]^{1.67}$$

$$(1) \quad b \quad T_2 = 560^\circ \text{R} \left[1 - 1.128 \times 10^{-4} \int_0^t \dot{W}_4 dt \right]^{0.67}$$

$$(2) \quad a \quad \ddot{W} = 1.36 (P_4 - 0.099 \dot{W}_4^2 - P_5)$$

$$(2) \quad b \quad \dot{W}_4 = \int_0^t W_4 dt$$

$$(3) \quad a \quad \therefore \dot{P}_5 = 0.0191 T_2 (\dot{W}_4 - \dot{W}_5)$$

$$(3) \quad b \quad P_5 = \int_0^t \dot{P}_5 dt + P_5 \text{ (I.C.)}$$

$$(4) \quad \therefore \dot{W}_5 = 0.323 \sqrt{^\circ \text{R}/\text{sec}} A_{e471} N_{S471} P_5 / \sqrt{T_2}$$

$$(5) \quad a \quad \therefore \dot{P}_6 = 0.538 T_2 (\dot{W}_5 - \dot{W}_6)$$

$$(5) \quad b \quad P_6 = \int_0^t \dot{P}_6 dt + P_6 \text{ (I.C.)}$$

$$(6) \quad a \quad \therefore \dot{W}_6 = 0.323 A_{e78} N_{S78} P_6 / \sqrt{T_2}$$

$$(6) \quad b \quad \dot{W}_6 \geq 0 \quad (\text{Since 50CHV685 is immediately downstream})$$

$$(7) \quad a \quad \therefore \dot{P}_{12\text{GHe}} = 0.4305 T_2 (\dot{W}_6 - \dot{W}_{12\text{GHe}})$$

$$(7) \quad b \quad P_{12\text{GHe}} = \int_0^t \dot{P}_{12\text{GHe}} dt + P_{12} \text{ (I.C.)}$$

$$(8) \quad a \quad \dot{W}_{12\text{GHe}} = 0.323 (A_{e454} + A_{e460}) \frac{N_{S454//460}}{\sqrt{T_2}} (P_{12\text{GHe}} - 0.011 \dot{W}_{12\text{GHe}}^2)$$

$$(8) \quad b \quad \dot{W}_{12\text{GHe}} \geq 0 \text{ (Since 50CHV1721 is immediately downstream)}$$

$$(9) \quad a \quad \therefore \dot{P}_{13\text{GHe}} = 0.1128 T_2 (\dot{W}_{12\text{GHe}} - \dot{W}_{13\text{GHe}})$$

$$(9) \quad b \quad P_{13\text{GHe}} = \int_0^t \dot{P}_{13\text{GHe}} dt + P_{13} \text{ (I.C.)}$$

$$(10) \quad a \quad \therefore \dot{W}_{13\text{GHe}} = 0.323 A_{e\text{CDSV}} \frac{N_{\text{SCDSV}}}{\sqrt{T_2}} (P_{13\text{GHe}} - 0.0919 \dot{W}_{13\text{GHe}}^2)$$

$$(10) \quad b \quad \dot{W}_{13\text{GHe}} \geq 0 \text{ (Since CDCHV immediately follows CDSV)}$$

$$(11) \quad N_{\text{SCDSV}} \text{ (GHe)} = f \left(\frac{P_{13\text{GHe}} - 0.0919 \dot{W}_{13\text{GHe}}^2 - P_{e3}}{P_{13\text{GHe}} - 0.0919 \dot{W}_{13\text{GHe}}^2} \right)$$

$$(12) \quad N_{S78} = f \left(\frac{P_6 - P_{12\text{GHe}}}{P_6} \right)$$

$$(13) \quad N_{S471} = f \left(\frac{P_5 - P_6}{P_5} \right)$$

$$(14) \quad N_{S454//460} = f \left(\frac{P_{12GHe} - 0.011 \dot{W}_{12GHe} - P_{13GHe}}{P_{12GHe} - 0.011 \dot{W}_{12GHe}^2} \right)$$

$$(15) \quad A_{eCDSV} = f(\theta_{CDSV})$$

$$(16) \quad a \quad \frac{\theta_{CDSV}}{\theta_{CDSVD}} (S) = \frac{1}{(0.02S^2 + 0.14S + 1)}$$

$$(16) \quad b \quad \theta_{CDSV} = \int_0^t \ddot{\theta}_{CDSV}^{DT} dt$$

NOTE: These equations are common to all coolants.

$$(16) \quad c \quad \theta_{CDSV} = \int_0^t \dot{\theta}_{CDSV} dt$$

$$(17) \quad a \quad \frac{L_{78}}{L_{78D}} (S) = \frac{1}{(1 + 0.35S)(1 + 0.40S)}$$

$$(17) \quad b \quad \dot{L}_{78} = \int_0^t \ddot{L}_{78} dt$$

$$(17) \quad c \quad L_{78} = \int_0^t \dot{L}_{78} dt$$

$$(18) \quad L_{471} = \int_0^t \dot{L}_{471} dt$$

$$(19) \quad a \quad \frac{L_{454}}{L_{454D}} (S) = \frac{1}{(1 + 0.40S) (1 + 0.45S)}$$

$$(19) \quad b \quad \dot{L}_{454} = \int_0^t \ddot{L}_{454} dt$$

$$(19) \quad c \quad L_{454} = \int_0^t \dot{L}_{454} dt$$

$$(20) \quad A_{e454} = f (L_{454})$$

$$(21) \quad A_{e460} = f (L_{460})$$

$$(22) \quad a \quad \frac{L_{460}}{L_{460D}} (S) = \frac{1}{(1 + 0.40S) (1 + 0.45S)}$$

$$(22) \quad b \quad \dot{L}_{460} = \int_0^t \ddot{L}_{460} dt$$

$$(22) \quad c \quad L_{460} = \int_0^t \dot{L}_{460} dt$$

$$(23) \quad A_{e78} = f (L_{78})$$

$$(24) \quad A_{e471} = f (L_{471})$$

3.2.2.8 COMPLIANCE PARAMETER, $\frac{\beta}{\rho_f}$ -

3.2.2.8.1 General:

$\frac{\beta}{\kappa \rho_m} = C^2$, Where C = Sonic velocity of medium under given conditions.

but $C^2 = \kappa gRT$ for gaseous media.

3.2.2.8.2 Liquid Coolants

LH₂: @ P = 700 PSIA

C = 4200 ft./sec REF: (AGC 6586T Property of Princ. Cryogenics)

$$\therefore \frac{\beta}{g_{pm}} = \frac{\beta}{\rho_f} = \frac{C^2}{g} = \frac{(4200)^2 \text{ ft.}^2/\text{sec}^2}{32.2 \text{ ft./sec}^2} \times 12 \text{ in./ft.}$$

$\left. \frac{\beta}{\rho_f} \right _{\text{LH}_2} = 6.59 \times 10^6 \text{ in.}$
--

LN₂: @ 250 PSIA

C = 2100 ft./sec REF: (AGC 6586T Property of Princ. Cryogenics)

$$\frac{\beta}{\rho_f} = \frac{C^2}{g} = \frac{2100^2 \text{ ft.}^2/\text{sec}^2}{32.2 \text{ ft./sec}^2} \times 12 \text{ in./ft} =$$

$\left. \frac{\beta}{\rho_f} \right _{\text{LN}_2} = \frac{C^2}{g} = 1.647 \times 10^6 \text{ in.}$

3.2.2.8.3 Gaseous Coolants

$$\underline{\text{GH}_2}: \quad \frac{\beta}{\rho_f} = \frac{C^2}{g} = \frac{kgRT}{g}$$

$$k = 1.4$$

$$R = 767 \text{ ft}/^\circ\text{R}$$

$$\therefore \frac{\beta}{k\rho_f} \Big|_{\text{GH}_2} = (767 \text{ ft}/^\circ\text{R}) \cdot T$$

$$\underline{\text{GHe}}: \quad \frac{\beta}{\rho_f} = \frac{C^2}{g} = \frac{kgRT}{g}$$

$$k = 1.67$$

$$R = 387 \text{ ft}/^\circ\text{R}$$

$$\therefore \frac{\beta}{k\rho_f} \Big|_{\text{GHe}} = (387 \text{ ft}/^\circ\text{R}) \cdot T$$

3.2.2.8.4 Pressure Equation Derivation

Reference: "Fluid Mechanics," R. C. Binder, Second Edition, 1949, Section 116, Bulk Modulus, Prentice Hall.

$$\beta = - \frac{d P}{d v/v}$$

$$C = \sqrt{\frac{\beta}{\rho_m}} \text{ for adiabatic process } C = \sqrt{\frac{kP}{\rho_m}}$$

$$C = \sqrt{kgRT} \text{ ideal gas}$$

$$P_v = RT$$

$$P = \rho_m RT = W/\text{Vol } RT = W/\text{Vol } C^2/\text{kg}$$

$$\begin{aligned}
P &= W/Vol \frac{\beta}{\rho_m g k} & \rho_m g &= \rho_f (lb/ft^3) \\
&= W/Vol \frac{\beta}{\rho_f k} & W &= \int_0^t (\dot{W}_{in} - \dot{W}_{out}) dt \\
\therefore P &= \frac{\beta}{\rho_f k} \frac{1}{Vol} \int_0^t (\dot{W}_{in} - \dot{W}_{out}) dt + P \text{ (I.C.)}
\end{aligned}$$

3.2.2.8.5 Definition of Reynolds Number of Pipes

$$N_{RC} = \frac{\rho_m \text{ Vel Diam}}{\mu} \quad \text{where } \rho_m = \text{Mass Density, } \frac{lbm}{ft^3}$$

Vel = Fluid Velocity, ft/sec

Diam = Pipe Diameter, ft

μ = Absolute Viscosity, $\frac{lbm \text{ sec}}{ft^2}$

but $\frac{\mu}{\rho} = \nu$ = Kinematic Viscosity, ft^2/sec

$$N_{RC} \equiv \frac{\text{Vel Diam}}{\nu}$$

and $\text{Vel} = \frac{\dot{W}}{A \rho_f}$

where $\dot{W}$ = Weight Flow Rate
= (lb/sec)

A = Area of Pipe
= (ft^2)

ρ_f = Weight Density
= (lb/ft^3)

$$\therefore N_{Re} \equiv \frac{\text{Diam } \dot{W}}{\nu \rho_f A}$$

3.2.2.9 System Equations

3.2.2.9.1 GHe Equation Derivation

3.2.2.9.1.1 GHe Line Lumps - Fluid Resistances

For GH_e @ 560° 2500 psia

$$\rho_f = 1.67 \text{ lb/ft}^3$$

$$v = 14.6 \times 10^{-6} \text{ ft}^2/\text{sec}$$

$$\dot{W}_{\max} = 50 \text{ lb/sec}$$

$$= \frac{d \dot{W}}{v \rho_f A}$$

For Lump 1 (GH_e manifold to 50 PCV 449) -

$$\text{Pipe I.D.} = 0.432 \text{ ft}$$

$$l = 502.34 \text{ ft}$$

$$\text{Area} = 0.147 \text{ ft}^2$$

$$\epsilon/d = 0.0001$$

Thus -

$$N_{RE} = \frac{0.432 \text{ ft} \times 50 \text{ lb/sec}}{14.6 \times 10^{-6} \text{ ft}^2/\text{sec} \times 1.67 \text{ lb/ft}^3 \times 0.147 \text{ ft}^2}$$

$$= 6.027 \times 10^6$$

$$\therefore f = 0.014$$

$$\Delta p \text{ (lb/ft}^2\text{)} = f \left(\frac{\delta}{d}\right) \frac{\dot{W}^2}{2 \rho_f A^2 g} = K'_{R34} \dot{W}^2$$

$$K'_{R34} = f \left(\frac{Z}{d}\right) \frac{1}{2 \rho_f A^2 g} = \frac{1.4 \times 10^{-2} \times 502.34 \text{ ft}}{2(0.432 \text{ ft}) \times 1.67 \text{ lb/ft}^3 \times (0.147)^2 \text{ ft}^4} \times$$

$$1/32.2 \text{ ft/sec}^2$$

$$K'_{R34} = 7.00 \frac{\text{sec}^2}{\text{lb ft}^2} = 0.049 \frac{\text{sec}^2}{\text{lb in.}^2} \quad (\text{Due to Line only})$$

In Lump 1, the ΔP due to fittings:

$$K_{f34} = \frac{\Sigma K_{f1}}{2 \rho_f g A^2} = \frac{\Sigma K_{f1}}{1.67 (32.2) (.147)^2} \frac{\text{sec}^2}{\text{lb ft}^2}$$

$$= 0.43 \Sigma K_{f1} \frac{\text{sec}^2}{\text{lb ft}^2}$$

In Lump 1 there are 14 - 90°, 4-Tees, 2-V

$$\Sigma K_{f1} = 14(0.67) + 4(1.75) + 2 (0.25)$$

$$= 9.4 + 7 + 0.5 = 16.9$$

Thus -

$$K_{f34} = 0.43(16.58) \frac{\text{sec}^2}{\text{lb ft}^2} \times \frac{\text{ft}^2}{144 \text{ in.}^2} = 0.050 \frac{\text{sec}^2}{\text{lb in.}^2}$$

and

$$K_{R34} = K'_{R34} + K_{f34} = 0.049 + 0.050 =$$

$$K_{R34} = 0.099 \frac{\text{sec}^2}{\text{lb in.}^2}$$

Lump 2 has only a compliance, resistance is incorporated into Lump 3.

For Lump 3 -

$$K_{R39} = K'_{R39} + K_{F39}$$

Where K'_{R39} = Line Coefficient

K_{F39} = Fittings Coefficient

N_{Re} is same as for Lump 1 since:

$$\therefore f = 0.014$$

$$\epsilon/d = 0.0004$$

$$d = 0.432 \text{ ft}$$

$$A = 0.147 \text{ ft}^2$$

$$v = 14.6 \times 10^{-6} \text{ ft}^2/\text{sec}$$

$$\therefore K'_{R39} = \frac{1.6 \times 10^{-2} \times (25 + 16)}{2(0.432)(1.67)(.147)^2(32.2)(144)} \frac{\text{sec}^2}{\text{lb in.}^2}$$

$$K'_{R39} = 0.010 \frac{\text{sec}^2}{\text{lb in.}^2}$$

$$K_{F39} = \frac{\sum K_f^3}{2 \rho_f g A^2} = 0.010 \sum K_{f3}$$

In Lumps 2 and 3 there are: 3- 90°, 6-Tees, 1-CHU, 2-V

$$\therefore \sum K_{f3} = 3(0.67) + 6(1.75) + 1(3.0) + 2(0.25) = 16$$

$$\therefore K_{f39} = \frac{0.010(16)}{144} = 0.001 \frac{\text{sec}^2}{\text{lb in.}^2}$$

$$\therefore K_{R39} = 0.010 + 0.001 =$$

$$K_{R39} = 0.011 \frac{\text{sec}^2}{\text{lb in.}^2}$$

For Lump 4 -

$$K_{R41} = K'_{R41} + K_{F41}$$

$$N_{RC} = \frac{d \dot{W}}{v \rho_f A}$$

There are two section of line:

$$\begin{aligned} d_1 &= 0.48 \text{ ft} \\ (1) \text{ } 36 \text{ ft, } A_1 &= 0.147 \text{ ft}^2 \\ (2) \text{ } 66 \text{ ft, } A_2 &= 0.125 \text{ ft}^2 \\ d_2 &= 0.397 \text{ ft} \end{aligned}$$

$$N_{Re(1)} = \frac{.48 \times 50}{14.6 \times 10^{-6} (1.67) (.147)} = 6.70 \times 10^6$$

$$\therefore f_{(1)} = 0.014$$

$$N_{Re(2)} = \frac{.397 \times 50}{(.125) 14.6 \times 10^{-6} (1.67)} = 6.51 \times 10^6$$

$$\therefore f_{(2)} = 0.012$$

$$\begin{aligned} \therefore K'_{R41} &= \frac{.012}{2(1.67)(32.2)(144)} \times \left[\frac{(1) \text{ } 36}{(.48)(.147)^2} + \frac{(2) \text{ } 66}{(.397)(.125)^2} \right] \frac{\text{sec}^2}{\text{lb in.}^2} \\ &= 7.75 \times 10^{-7} (3472 + 10,640) \end{aligned}$$

$$K'_{R41} = (7.75 \times 10^{-7}) (1.411 \times 10^4)$$

$$K'_{R41} = 0.0109 \frac{\text{sec}^2}{\text{lb in.}^2}$$

In Lump 4 there are - 4 - $\boxed{90^\circ}$ (2 in section (1))
 3 - T (in section (1))
 2 $\boxed{45^\circ}$ (in section (1))
 2 - CHV (1 in section (1))
 1 - V
 3 - Bellows (K = 2.5)

$$\begin{aligned}
 K_{F41} &= \frac{\Sigma K_{f4}}{2P_f g A^2} \\
 &= \left[\frac{\Sigma K_{f4(1)}}{A_{(1)}^2} + \frac{\Sigma K_{f4(2)}}{A_{(2)}^2} \right] \frac{1}{2\rho_f g} \\
 K_{F41} &= \frac{1}{2(1.67)(32.2)} \left[\frac{2(0.67) + 3(1.75) + 2(0.40) + 1(3.0)}{(.147)^2} + \frac{3(2.5) + 1(.25) + 1(3.0) + 2(0.67)}{(.125)^2} \right] \\
 &= \frac{1}{(3.34)(32.2)} \left(\frac{10.39}{.147^2} + \frac{13.09}{(.125)^2} \right) = \frac{481 + 775}{(3.34)(32.2)} \\
 &= \frac{1092}{144(3.34)(32.2)} = 0.131 \frac{\text{sec}^2}{\text{in.}^2 \text{ lb}}
 \end{aligned}$$

Thus - $K_{R41} = 0.0109 + 0.081 =$

$$K_{R41} = 0.0919 \frac{\text{sec}^2}{\text{in.}^2 \text{ lb}}$$

3.2.9.1.2 GHe Physical Equations

$$(1) \ a \quad P_4 = P_4(o) \left[\frac{w_4(t)}{w_4(o)} \right]^{1.67} \quad \rho_{\text{GHe}} \Big|_{\substack{T = 100^\circ\text{F} \\ P = 2500 \text{ psia}}} = 1.67 \text{ lb/ft}^3$$

$$w_4(t) = w_4(o) - \int_0^t \dot{w}_4(t) dt$$

$$\begin{aligned} w_4(o) &= [3(1770)] \ 1.67 \text{ lb} \\ &= 8868 \text{ lb} \end{aligned}$$

Thus-

$$P_4 = 2500 \text{ psia} \left[1 - 1.128 \times 10^{-4} \int_0^t \dot{w}_4 dt \right]^{1.67}$$

$$(1) \ b \quad T_2 = T_2(o) \left[\frac{\dot{w}_4(t)}{w_4(o)} \right]^{0.67}$$

$$T_2 = 560^\circ\text{R} \left[1 - 1.128 \times 10^{-4} \int_0^t \dot{w}_4 dt \right]^{0.67}$$

(assume all 3 vessels are at same temp, T_2)

$$(2) \text{ a } \ddot{W}_4 = K_{33} (P_4 - K_{R34} \dot{W}_4^2 - P_5)$$

$$K_{R34} = 0.099 \frac{\text{sec}^2}{\text{in.}^2 \text{ lb}} \quad (\text{See GHE Line Lumps})$$

$$\begin{aligned} K_{33} &= \frac{Ag}{l} = \frac{0.147 \times 32.2}{502.34 \times \text{sec}^2} \times 144 \text{ in.}^2 \\ &= 1.36 \frac{\text{in.}^2}{\text{sec}^2} \end{aligned}$$

Thus -

$$\ddot{W}_4 = 1.36 (P_4 - 0.099 \dot{W}_4^2 - P_5)$$

$$(2) \text{ b } \dot{W}_4 = \int_0^t \ddot{W}_4 dt$$

$$(3) \text{ a } \dot{P}_5 = K_{36} T_2 (\dot{W}_5 - \dot{W}_4)$$

$$T_2 K_{36} = \frac{\beta}{k \rho f} \frac{1}{\text{Vol}}$$

$$\frac{\beta}{k \rho f} = 647 T_2 \text{ ft}/1.67^\circ\text{R} \quad (\text{See Equation Derivation, General})$$

$$\begin{aligned} \therefore T_2 K_{36} &= \frac{647 T_2}{1.67^\circ\text{R}} \times \frac{1}{141.06 \text{ ft}^3} \times \frac{1 \text{ ft}^2}{144 \text{ in.}^2} \\ &= 0.0191 T_2 \text{ in.}^2 \text{ }^\circ\text{R}^{-1} \end{aligned}$$

$$\therefore \dot{P}_5 = 0.0191 T_2 (\dot{W}_4 - \dot{W}_5)$$

$$(3) \text{ b } P_5 = \int_0^t \dot{P}_5 dt + P_5 \text{ (I.C.)}$$

$$(4) \quad \dot{W}_5 = K_S A_{e471} N_{S471} P_5 / \sqrt{T_2}$$

$$K_S = \text{Smith's Constant (See Equation Derivation, General)}$$

$$= 0.323 \sqrt{^\circ R / \text{sec}}$$

$$\dot{W}_5 = 0.323 \sqrt{^\circ R / \text{sec}} A_{e471} N_{S471} P_5 / \sqrt{T_2}$$

$$(5) a \quad \dot{P}_6 = K_{37} T_2 (\dot{W}_5 - \dot{W}_6)$$

$$T_2 K_{37} = \frac{\beta}{k \rho_f} \frac{1}{\text{Vol}_2} \quad \text{Vol}_2 = \text{Vol of Lump 2}$$

$$= 5 \text{ ft}^3 \quad (\text{See "GHe Line Lumps"})$$

$$= \frac{647 T_2}{1.67^\circ R} \times \frac{1}{5 \text{ ft}^3} \times \frac{1 \text{ ft}^2}{144 \text{ in.}^2}$$

$$= 0.538 T_2 \text{ in.}^{-2} \text{ } ^\circ R^{-1}$$

$$\dot{P}_6 = 0.538 T_2 (\dot{W}_5 - \dot{W}_6)$$

$$(5) b \quad P_6 = \int_0^t \dot{P}_6 dt + P_6 \text{ (I.C.)}$$

$$(6) a \quad \dot{W}_6 = K_S A_{e78} N_{S78} P_6 / \sqrt{T_2} \quad K_{SGHe} = 0.323 \frac{^\circ R^{1/2}}{\text{sec}}$$

$$\therefore \dot{W}_6 = 0.323 A_{e78} N_{S78} P_6 / \sqrt{T_2}$$

$$(6) b \quad \dot{W}_6 \geq 0 \quad (\text{Since 50CHV685 is immediately downstream})$$

$$(7) \text{ a } \dot{P}_{12\text{GHe}} = K_{38} T_2 (\dot{W}_6 - \dot{W}_{12\text{GHe}})$$

$$T_2 K_{38} = \frac{\beta}{k = \rho_f} \frac{1}{\text{Vol}_3} \quad \text{Vol}_3 = \text{Vol of Lump 3} \\ = 6.25 \text{ ft.}^3$$

$$= \frac{647 T_2}{1.67^\circ\text{R}} \times \frac{1}{6.25 \text{ ft}^3} \times \frac{1 \text{ ft}^2}{144 \text{ in.}^2}$$

$$= 0.4305 T_2 \text{ in.}^{-2} \text{ }^\circ\text{R}^{-1}$$

$$\therefore \dot{P}_{12\text{GHe}} = 0.4305 T_2 (\dot{W}_6 - \dot{W}_{12\text{GHe}})$$

$$(7) \text{ b } P_{12\text{GHe}} = \int_0^t \dot{P}_{12\text{GHe}} dt + P_{12} \text{ (I.C.)}$$

$$(8) \text{ a } \dot{W}_{12\text{GHe}} = K_S (A_{e454} + A_{3460}) \frac{N_{S454/460}}{\sqrt{T_2}} (P_{12\text{GHe}} - K_{R39} \dot{W}_{12\text{GHe}}^2)$$

$$K_S = \text{Smith's Constant} = 0.323 \text{ }^\circ\text{R}^{1/2}/\text{sec}$$

$$K_{R39} = 0.011 \frac{\text{sec}^2}{\text{lb in.}^2} \quad (\text{See GHe Line Lumps})$$

Thus -

$$\dot{W}_{12\text{GHe}} = 0.323 (A_{e454} + A_{e460}) \frac{N_{S454/460}}{\sqrt{T_2}} (P_{12\text{GHe}} - 0.011 \dot{W}_{12\text{GHe}}^2)$$

$$(8) \text{ b } \dot{W}_{12\text{GHe}} \geq 0 \quad (\text{Since 50CHV721 is immediately downstream})$$

$$(9) \text{ a } \dot{P}_{13\text{GHe}} = K_{40} T_2 (\dot{W}_{12\text{GHe}} - \dot{W}_{13\text{GHe}})$$

$$T_2 K_{40} = \frac{\beta}{k \rho_f} \frac{1}{\text{Vol}_4} \quad \text{Vol}_4 = \text{Vol of Lump 4} \\ = 23.86 \text{ ft.}^3$$

$$\begin{aligned}
&= \frac{647 T_2}{1.67^\circ R} \times \frac{1}{23.86 \text{ ft.}^3} \times \frac{1 \text{ ft}^2}{144 \text{ in.}^2} \\
&= 0.1128 T_2 \text{ }^\circ R^{-1} \text{ in.}^{-2}
\end{aligned}$$

$$\therefore \dot{P}_{13\text{GHe}} = 0.1128 T_2 (\dot{W}_{12\text{GHe}} - \dot{W}_{13\text{GHe}})$$

$$(9) \text{ b } P_{13\text{GHe}} = \int \dot{P}_{13\text{GHe}} dt + P_{13} \text{ (I.C.)}$$

$$(10) \text{ a } \dot{W}_{13\text{GHe}} = K_S A_{\text{eCDSV}} \frac{N_{\text{SCDSV}}}{\sqrt{T_2}} (P_{13\text{GHe}} - K_{R41} \dot{W}_{13\text{GHe}}^2)$$

$$K_S = \text{Smith's Constant} = 0.323 \text{ }^\circ R^{1/2}/\text{sec}$$

$$K_{R41} = 0.0919 \frac{\text{sec}^2}{\text{in.}^2 \text{ lb}} \text{ (See GHe Line Lumps)}$$

$$\therefore \dot{W}_{13\text{GHe}} = 0.323 A_{\text{eCDSV}} \frac{N_{\text{SCDSV}}}{\sqrt{T_2}} (P_{13\text{GHe}} - 0.150 \dot{W}_{13\text{GHe}}^2)$$

$$(10) \text{ b } \dot{W}_{13\text{GHe}} \geq 0 \text{ (Since CDCHV immediately follows CDSV)}$$

$$(11) \quad N_{\text{SCDSV}}(\text{GHe}) = f \left(\frac{P_{13\text{GHe}} - K_{R41} \dot{W}_{13\text{GHe}}^2 - P_{e3}}{P_{13\text{GHe}} - K_{R41} \dot{W}_{13\text{GHe}}^2} \right)$$

$$N_{\text{SCDSV}}(\text{GHe}) = f \left(\frac{P_{13\text{GHe}} - 0.0919 \dot{W}_{13\text{GHe}}^2 - P_{e3}}{P_{13\text{GHe}} - 0.0919 \dot{W}_{13\text{GHe}}^2} \right)$$

$$(12) \quad N_{S78} = f \left(\frac{P_6 - P_{12GHe}}{P_6} \right)$$

$$(13) \quad N_{S471} = f \left(\frac{P_5 - P_6}{P_5} \right)$$

$$(14) \quad N_{S454//460} = f \left(\frac{P_{12GHe} - K_{R39} \dot{W}_{12GHe}^2 - P_{13GHe}}{P_{12GHe} - K_{R39} \dot{W}_{12GHe}^2} \right)$$

$$= f \left(\frac{P_{12GHe} - 0.011 \dot{W}_{12GHe}^2 - P_{13GHe}}{P_{12GHe} - 0.011 \dot{W}_{12GHe}^2} \right)$$

$$(15) \quad A_{eCDSV} = f(\theta_{CDSV}) \quad (\text{NOTE: These are common equations for all coolants})$$

(See Fig 3.5)

$$(16) \quad a \quad \frac{\theta_{CDSV}}{\theta_{CDSVD}} (s) = \frac{1}{(0.02 s^2 + 0.14 s + 1)}$$

$$(16) \quad b \quad \dot{\theta}_{CDSV} = \int_0^t \ddot{\theta}_{CDSV} dt$$

$$(16) \quad c \quad \theta_{CDSV} = \int_0^t \dot{\theta}_{CDSV} dt$$

$$(17) \quad a \quad \frac{L_{78}}{L_{78D}} (s) = \frac{1}{(1 + 0.35S)(1 + 0.40S)}$$

$$(17) \quad b \quad \dot{L}_{78} = \int_0^t \ddot{L}_{78} dt$$

$$(17) \quad c \quad \dot{L}_{78} \quad = \quad \int_0^t \dot{L}_{78} \, dt$$

$$(18) \quad L_{471} \quad = \quad \int_0^t \dot{L}_{471} \, dt$$

$$(19) \quad a \quad \frac{L_{454}}{L_{454D}} \, (s) \quad = \quad \frac{1}{(1 + 0.40S) (1 + 0.45S)}$$

$$(19) \quad b \quad \dot{L}_{454} \quad = \quad \int_0^t \ddot{L}_{454} \, dt$$

$$(19) \quad c \quad L_{454} \quad = \quad \int_0^t \dot{L}_{454} \, dt$$

$$(20) \quad A_{e454} \quad = \quad f \, (L_{454})$$

$$(21) \quad A_{e460} \quad = \quad f \, (L_{460})$$

$$(22) \quad a \quad \frac{L_{460}}{L_{460D}} \, (s) \quad = \quad \frac{1}{(1 + 40S) (1 + 0.45S)}$$

$$(22) \quad b \quad \dot{L}_{460} \quad = \quad \int_0^t \ddot{L}_{460} \, dt$$

$$(22) \quad c \quad L_{460} \quad = \quad \int_0^t \dot{L}_{460} \, dt$$

$$(23) \quad A_{e78} = f(L_{78})$$

$$(24) \quad A_{e471} = f(L_{471})$$

3.2.2.9.1.3 Summary of GH₂ Equations

$$(1) \text{ a } P_7 = P_7(0) = 2500 \text{ psia}$$

$$(1) \text{ b } T_3 = T_3(0) = 560^\circ\text{R}$$

$$(2) \text{ a } \dot{W}_7 = 0.1402 N_{S201} A_{e201} P_7 / \sqrt{T_e}$$

$$(2) \text{ b } \dot{W}_7 \geq 0 \text{ (Since 50CHV117 immediately follows 50RSV201)}$$

$$(3) \text{ a } \dot{P}_8 = 0.0463 T_3 (\dot{W}_7 - \dot{W}_8)$$

$$(3) \text{ b } P_8 = \int \dot{P}_8 dt + P_8 \text{ (I.C.)}$$

$$(4) \dot{W}_8 = 0.1402 A_{e251} \dot{N}_{S251} (P_8 - 0.1812 \dot{W}_8^2) / \sqrt{T_3}$$

$$(5) \text{ a } \dot{P}_{14} = 1.065 T_3 (\dot{W}_8 - \dot{W}_{15})$$

$$(5) \text{ b } P_{14} = \int \dot{P}_{14} dt + P_{14} \text{ (I.C.)}$$

$$(6) \text{ a } \ddot{W}_{15} = 4.02 (P_{14} - 0.1014 \dot{W}_{15}^2 - P_{12GH_2})$$

$$(6) \text{ b } \dot{W}_{15} = \int \ddot{W}_{15} dt$$

$$(6) \text{ c } W_{15} \geq 0 \text{ (Since lump is terminated at 50CHV496)}$$

$$(7) \text{ a } \dot{P}_{12GH_2} = 0.853 T_3 (\dot{W}_{15} - \dot{W}_{12GH_2})$$

$$(7) \text{ b } P_{12GH_2} = \int \dot{P}_{12GH_2} dt + P_{12} \text{ (I.C.)}$$

$$(8) \text{ a } \dot{W}_{12GH_2} = \frac{0.1402 (A_{e454} + A_{e460}) N_{S454/460} (P_{12GH_2} - 0.0977 \dot{W}_{12GH_2}^2)}{T_3}$$

$$(8) \text{ b } \dot{W}_{12GH_2} \geq 0 \text{ (Since 50CHV1721 immediately follows 50RSV454/50RSV460)}$$

$$(9) \text{ a } \dot{P}_{13GH_2} = 0.223 T_3 (\dot{W}_{12GH_2} - \dot{W}_{13GH_2})$$

$$(9) \text{ b } P_{13GH_2} = \int_0^t \dot{P}_{13GH_2} dt + P_{13} \text{ (I.C.)}$$

$$(10) \text{ a } \dot{W}_{13GH_2} = 0.1402 A_{eCDSV} \frac{N_{SCDSV}}{\sqrt{T_3}} (P_{13GH_2} - 0.1037 \dot{W}_{13GH_2}^2)$$

$$(10) \text{ b } \dot{W}_{13GH_2} \geq 0 \text{ (Since CDSV is followed by CDSHV)}$$

$$(11) N_{SCDSV} = f \left(\frac{P_{13GH_2} - 0.1037 \dot{W}_{13GH_2}^2 - P_{e3}}{P_{13GH_2} - 0.1037 \dot{W}_{13GH_2}^2} \right)$$

$$(12) N_{S201} = f \left(\frac{P_7 - P_8}{P_7} \right)$$

$$(13) N_{S251} = f \left(\frac{P_8 - 0.1812 \dot{W}_8^2 - P_{14}}{P_8 - 0.1812 \dot{W}_8^2} \right)$$

$$(14) N_{S454/460} = f \left(\frac{P_{12GH_2} - 0.0977 \dot{W}_{12GH_2}^2 - P_{13GH_2}}{P_{12GH_2} - 0.0977 \dot{W}_{12GH_2}^2} \right)$$

$$(15) \quad A_{eCDSV} = f (\Theta_{CDSV})$$

$$(16) \text{ a} \quad \frac{\Theta_{CDSV}}{\Theta_{CDSVD}} (S) = \frac{1}{(0.02S^2 + 0.14S + 1)}$$

NOTE: These equations
are common for all
coolants.

$$(16) \text{ b} \quad \dot{\Theta}_{CDSV} = \int_0^t \ddot{\Theta}_{CDSV} dt$$

$$(16) \text{ c} \quad \Theta_{CDSV} = \int_0^t \dot{\Theta}_{CDSV} dt$$

$$(17) \text{ a} \quad \frac{L_{201}}{L_{201D}} (S) = \frac{1}{(1 + 0.35S)(1 + 0.40S)}$$

$$(17) \text{ b} \quad \dot{L}_{201} = \int_0^t \ddot{L}_{201} dt$$

$$(17) \text{ c} \quad L_{201} = \int_0^t \dot{L}_{201} dt$$

$$(18) \quad L_{251} = \int_0^t \dot{L}_{251} dt$$

$$(19) \quad A_{e201} = f (L_{201})$$

$$(20) \quad A_{e251} = f (L_{251})$$

$$(21) \quad A_{e454} = f (L_{454})$$

$$(22) \quad A_{e460} = f (L_{460})$$

$$(23) \text{ a} \quad \frac{L_{454}}{L_{454D}} (S) = \frac{1}{(1 + 0.40S) (1 + 0.45S)}$$

$$(23) \text{ b} \quad \dot{L}_{454} = \int_0^t \ddot{L}_{454} dt$$

$$(23) \text{ c} \quad L_{454} = \int_0^t \dot{L}_{454} dt$$

$$(24) \text{ a} \quad \frac{L_{460}}{L_{460D}} (S) = \frac{1}{(1 + 0.40S) (1 + 0.45S)}$$

$$(24) \text{ b} \quad \dot{L}_{460} = \int_0^t \ddot{L}_{460} dt$$

$$(24) \text{ c} \quad L_{460} = \int_0^t \dot{L}_{460} dt$$

3.2.2.9.1.4 GH_2 Equation Derivation

3.2.2.9.1.4.1 GH_2 Line Lumps - Fluid Resistances

For GH_2 : @ 560°R, 2500 PSIA

$$\rho_f = 0.84 \text{ lb/ft.}^3$$

$$v = 7.15 \times 10^{-6} \text{ ft.}^2/\text{sec}$$

$$\dot{W}_{\text{max.}} = 10 \text{ lb/sec.}$$

$$N_{\text{Re}} = \frac{d \dot{W}}{v \rho_f A}$$

For Lump 1 -

$$\text{Pipe I.D.} = 0.432 \text{ ft.}$$

$$\text{Area} = 0.147 \text{ ft.}^2$$

$$\epsilon/d = 0.0001$$

$$l = 632.67 \text{ ft.}$$

$$N_{\text{Re}1} = \frac{0.432 \text{ ft.} \times 10 \text{ lb/sec.}}{7.15 \times 10^{-6} \text{ ft.}^2/\text{sec.} \times 0.84 \text{ lb/ft.}^3 \times 0.147 \text{ ft.}^2} = 4.91 \times 10^6$$

$$\therefore f = 0.012$$

$$\Delta P \text{ lb/ft.}^2 = f \frac{1}{d} \frac{\dot{W}^2}{2 \rho_f A^2 g} = K'_{\text{R26}} \dot{W}^2$$

$$\therefore K'_{\text{R26}} = f \frac{1}{d} \frac{1}{2 \rho_f A^2 g} = \frac{1.2 \times 10^{-2} \times 632.67 \text{ ft.}}{2 (.432 \text{ ft}) \times \frac{0.84 \text{ lb}}{\text{ft.}^3} \times (.147)^2 \text{ ft.}^2 \times 32.2 \text{ ft.}} \frac{\text{sec.}^2}{\text{ft.}^2}$$

$$= 15.04 \frac{\text{sec.}^2}{\text{lb ft.}^2} = 0.104 \frac{\text{sec.}^2}{\text{lb in.}^2}$$

In Lump 1 there are 7 - $\angle 90^\circ$, 2 - $\angle 45^\circ$, 4 - T, 2 - V

$$K_{f26} = \frac{K_{f1}}{2 \rho_f g A_1^2} = \frac{12.99}{\frac{7(0.67) + 2(0.40) + 4(1.75) + 2(.25)}{2(.84)(32.2)(.147)^2(144)}} = 0.0772 \frac{\text{sec.}^2}{\text{lb in.}^2}$$

$$\therefore K_{R26} = K'_{R26} + K_{f26} = 0.104 + 0.0772$$

$$K_{R26} = 0.1812$$

For Lump 2 - $N_{Re2} = N_{Re1}$ since $d_1 = d_2$, $A_2 = A_1$

$$\epsilon/d = 0.0001$$

$$\therefore f = 0.012$$

$$K_{R29} = K'_{R29} + K_{f29}$$

$$K'_{29} = \frac{(.012)(17 \text{ ft.})}{2(.432 \text{ ft/})} \frac{\text{ft.}^3}{(0.84 \text{ lb})(0.0217 \text{ ft.}^4)(32.2 \text{ ft.})(144 \text{ in.}^2)} \frac{\text{sec.}^2 \text{ ft.}^2}{\text{lb in.}^2} = \frac{.204}{72.7} = 0.0028 \frac{\text{sec.}^2}{\text{lb in.}^2}$$

In Lump 2 there are: 1 - $\angle 90^\circ$, 2 - T, 1 - CHV

$$K_{f29} = \frac{\Sigma K_f^2}{2 \rho_f g A^2} = \frac{(0.67) + 2(1.75) + 3}{(2)(.84)(32.2)(.0217)(144)} = \frac{7.17}{(2)(.84)(32.2)(.0217)(144)} = 0.0986 \frac{\text{sec.}^2}{\text{lb in.}^2}$$

$$\therefore K_{R29} = 0.0028 + 0.0986 = 0.1014 \frac{\text{sec.}^2}{\text{lb in.}^2}$$

For Lump 3 - $N_{Re3} = N_{Re1}$ since $d_1 = d_3$, $A_1 = A_3$, $\epsilon/d = 0.001$

$$\therefore f = 0.012$$

$$K_{R31} = K'_{R31} + K_{f31}$$

$$\begin{aligned} K_{R31} &= \frac{(0.012)(16 \text{ ft.})}{2(.432 \text{ ft.})(0.84 \text{ E/ft.}^3)(32.2 \text{ ft.})(.0216 \text{ ft.}^4)(144 \text{ in.}^2)} \frac{\text{sec.}^2}{\text{ft.}^2} \\ &= \frac{.192}{72.7} = 0.0026 \frac{\text{sec.}^2}{\text{lb in.}^2} \end{aligned}$$

In Lump 3 there are: 3 - $\angle 90^\circ$, 6 - T, 1 - CHV, 2-V

$$\begin{aligned} K_{f3} &= \frac{\Sigma K}{2 \rho_f g A_3^2} = \frac{3(0.67) + 6(1.75) + 1(3.0) + 2(.25)}{2(.84)(32.2)(.0216)(144)} \\ &= \frac{16}{168.2} = 0.0951 \frac{\text{sec.}^2}{\text{lb in.}^2} \end{aligned}$$

$$\therefore K_{R31} = 0.0026 + 0.0951 = 0.0977$$

$$K_{R31} = 0.0977 \text{ sec.}^2/\text{in.}^2 \text{ lb}$$

For Lump 4 there are: 2 sections

Section (1)		Section (2)	
$l_1 = 36 \text{ ft.}$	$d_1 = .432 \text{ ft.}$	$l_2 = 66 \text{ ft.}$	$d_2 = .397 \text{ ft.}$
$A_1 = .147 \text{ ft.}^2$		$A_2 = .125 \text{ ft.}^2$	
$\angle 90^\circ = 2$		$\angle 90^\circ = 2$	
$\angle 45^\circ = 2$		$v = 1$	
T = 3		Bellows ($K_f = 2.5$) = 3	
CHV = 1			

$$N_{Re41} = N_{Re1} \text{ since } d_1 = d_4, A_1 = A_4$$

$$N_{Re42} = \frac{.397 \text{ ft.} \times 10 \text{ lb/sec.}}{7.15 \times 10^{-6} \text{ ft.}^2/\text{sec.} \times 0.84 \text{ lb ft.}^3 \times 0.125 \text{ ft.}^2} = 5.29 \times 10^6$$

$$\dot{v}_f = 0.012$$

$$\therefore K_{R33} = K'_{R33} + K_{f33}$$

$$K'_{R33} = K'_{R33} (2) + K'_{R33} (1)$$

$$= \frac{.012}{2(.84)(32.2)(144)} \times \left[\frac{36}{(.432)(.0216)} + \frac{66}{(.397)(.125)^2} \right]$$

$$= 1.54 \times 10^{-6} \left[3.86 \times 10^3 + 1.062 \times 10^4 \right]$$

$$= 2.23 \times 10^{-2} = 0.0223 \frac{\text{sec.}^2}{\text{lb in.}^2}$$

$$K_{f33} = K_{f33} (2) + K_{f33} (1)$$

$$= \frac{\Sigma K_{f(2)}}{2 \rho_f g A_4^2 (2)} + \frac{\Sigma K_{f(1)}}{2 \rho_f g A_4^2 (1)}$$

$$= \frac{1}{(2)(.84)(32.2)(144)} \frac{2(.67)+2(.40)+3(1.75)+3}{.0217}$$

$$+ \frac{3(2.5)+(.25)+2(.67)}{0.0156}$$

$$= 1.290 \times 10^{-4} \frac{1.34 + .8 + 5.25 + 3}{.0216} \frac{7.5 + .25 + 1.34}{0.0156}$$

$$= 1.290 \times 10^{-4} (4.81 \times 10^{+2} + 1.50 \times 10^{+2}) = 8.14 \times 10^{-2} \frac{\text{sec.}^2}{\text{lb in.}^2}$$

$$\therefore K_{R33} = 0.1037 \frac{\text{sec.}^2}{\text{lb in.}^2}$$

3.2.2.9.1.4.2 GH₂ Physical Equations

$$(1) \text{ a } P_7 = P_7(0) = 2500 \text{ psia}$$

Assume infinite source.

$$(1) \text{ b } T_3 = T_3(0) = 560^\circ\text{R}$$

$$(2) \text{ a } \dot{W}_7 = K_S N_{S201} P_7 / \sqrt{T_3}$$

$$K_S = \text{Smith's Constant} = 0.1402 \text{ for GH}_2$$

$$\dot{W}_7 = 0.1402 N_{S201} A_{e201} P_7 / \sqrt{T_3}$$

$$(2) \text{ b } \dot{W}_7 \geq 0 \text{ Since 50 CHV117 immediately follows 50RSV201.}$$

$$(3) \text{ a } \dot{P}_8 = K_{25} T_3 (\dot{W}_7 - \dot{W}_8)$$

$$T_3 K_{25} = \frac{\beta}{k\rho_f} \frac{1}{\text{Vol}_1}$$

$$\text{where Vol}_1 = \text{Vol of Lump 1} \\ = 115 \text{ ft}^3$$

$$= \frac{767 T_3}{115^\circ\text{R} \cdot 144 \text{ in.}^2}$$

$$= 0.0463$$

$$\frac{\beta}{k\rho_f} = 767 \text{ T ft}/^\circ\text{R}$$

$$P_8 = 0.0463 T_3 (\dot{W}_7 - \dot{W}_8)$$

$$(3) \text{ b } P_8 = \int \dot{P}_8 dt + P_8(\text{I.C.})$$

$$(4) \dot{W}_8 = K_S A_{e251} N_{S251} (P_8 - K_{R26} \dot{W}_8^2) / \sqrt{T_3}$$

$$K_S = 0.1402^\circ\text{R}^{1/2}/\text{sec}$$

$$K_{R26} = 0.1812 \text{ sec}^2/\text{lb in.}^2$$

$$\therefore \dot{W}_8 = 0.1402 A_{e251} N_{S251} (P_8 - 0.1812 \dot{W}_8^2) / \sqrt{T_3}$$

$$(5) \text{ a } \dot{P}_{14} = K_{27} T_3 (\dot{W}_8 - \dot{W}_{15})$$

$$T_3 K_{27} = \frac{\beta}{k \rho_f} \frac{1}{Vol_2} \quad \text{where } Vol_2 = \text{Vol of Lump 2} \\ = 5 \text{ ft}^3$$

$$= \frac{767 T_3 \text{ ft ft}^2}{^{\circ}R 5 \text{ ft}^3 144 \text{ in.}^2}$$

$$\dot{P}_{14} = 1.065 T_3 (\dot{W}_8 - \dot{W}_{15})$$

$$(5) \text{ b } P_{14} = \int_0^t \dot{P}_{14} dt + P_{14} \text{ (I.C.)}$$

$$(6) \text{ a } \ddot{W}_{15} = K_{28} (P_{14} - K_{R29} \dot{W}_{15}^2 - P_{12GH_2})$$

$$K_{R29} = 0.1014 \frac{\text{sec}^2}{\text{lb in.}^2} \quad (\text{See "GH}_2 \text{ Line Lumps"})$$

$$K_{28} = \frac{A_g}{l} = \frac{0.147 \times 32.2}{170 \text{ sec}^2} \times 144 \text{ in.}^2 \\ = 4.02 \text{ in.}^2/\text{sec}^2$$

$$\therefore \ddot{W}_{15} = 4.02 (P_{14} - 0.1014 \dot{W}_{15}^2 - P_{12GH_2})$$

$$(6) \text{ b } \dot{W}_{15} = \int_0^t W_{15} dt$$

$$(6) \text{ c } \dot{W}_{15} \geq 0 \quad \text{Since lump is terminated at 50CHV496.}$$

$$(7) \text{ a} \quad \dot{P}_{12GH_2} = K_{30} T_3 (\dot{W}_{15} - \dot{W}_{12GH_2})$$

$$T_3 K_{30} = \frac{\beta}{\rho_f k} \frac{1}{Vol_3} \quad Vol_3 = 6.25 \text{ ft}^3$$

$$= \frac{767 T_3 \text{ ft ft}^2}{^\circ R \text{ } 6.25 \text{ ft}^3 \text{ } 144 \text{ in.}^2}$$

$$= 0.853 T_3$$

$$\therefore \dot{P}_{12GH_2} = 0.853 T_3 (\dot{W}_{15} - \dot{W}_{12GH_2})$$

$$(7) \text{ b} \quad P_{12GH_2} = \int \dot{P}_{12GH_2} dt + P_{12} \text{ (I.C.)}$$

$$(8) \text{ a} \quad \dot{W}_{12GH_2} = \frac{K_S (A_{e454} + A_{e460}) N_{S454/460} (P_{12GH_2} - K_{R31} \dot{W}_{12GH_2}^2)}{\sqrt{T_3}}$$

$$K_S = 0.140^\circ R^{1/2}/\text{sec}$$

$$K_{R31} = 0.0977 \text{ sec}^2/\text{lb in.}^2$$

$$\therefore \dot{W}_{12GH_2} = \frac{0.1402 (A_{e454} + A_{e460}) N_{S454/460} (P_{12GH_2} - 0.0977 \dot{W}_{12GH_2}^2)}{\sqrt{T_3}}$$

$$(8) \text{ b} \quad \dot{W}_{12GH_2} \geq 0 \text{ Since } 50CHV1721 \text{ immediately follows } 50RSV454/50RSV460.$$

$$(9) \text{ a} \quad \dot{P}_{13GH_2} = K_{32} T_3 (\dot{W}_{12GH_2} - \dot{W}_{13GH_2})$$

$$K_{32} T_3 = \frac{\beta}{k\rho_f} \frac{1}{Vol_4} \quad Vol_4 = 23.86 \text{ ft}^3$$

$$= \frac{767 T_3}{^{\circ}R \ 23.86 \times 144 \text{ in.}^2}$$

$$= 0.223 T_3 \text{ } ^{\circ}R^{-1} \text{ in.}^{-2}$$

$$\therefore \dot{P}_{13GH_2} = 0.223 T_3 (\dot{W}_{12GH_2} - \dot{W}_{13GH_2})$$

$$(9) \text{ b} \quad P_{13GH_2} = \int \dot{P}_{13GH_2} dt + P_{13} \text{ (I.C.)}$$

$$(10) \text{ a} \quad \dot{W}_{13GH_2} = K_S A_{eCDSV} \frac{N_{SCDSV}}{\sqrt{T_3}} (P_{13GH_2} - K_{R33} \dot{W}_{13GH_2}^2)$$

$$K_S = 0.1402 \text{ } ^{\circ}R^{1/2}/\text{sec}$$

$$K_{R33} = 0.1037 \text{ sec}^2/\text{lb in.}^2$$

$$\therefore \dot{W}_{13GH_2} = 0.1402 A_{eCDSV} \frac{N_{SCDSC}}{\sqrt{T_3}} (P_{13GH_2} - 0.1037 \dot{W}_{13GH_2}^2)$$

$$(10) \text{ b} \quad \dot{W}_{13GH_2} \geq 0 \text{ Since CDSV is followed by CDSHV.}$$

$$(11) \quad N_{\text{SCDSV}} = f \left(\frac{P_{13\text{GH}_2} - K_{\text{R33}} \dot{W}_{13\text{GH}_2} - P_{\text{e3}}}{P_{13\text{GH}_2} - K_{\text{R33}} \dot{W}_{13\text{GH}_2}} \right)$$

$$K_{\text{R33}} = 0.1037 \text{ sec}^2/\text{lb in.}^2$$

$$\therefore N_{\text{SCDSV}} = f \left(\frac{P_{13\text{GH}_2} - 0.1037 \dot{W}_{13\text{GH}_2}^{\text{L}} - P_{\text{e3}}}{P_{13\text{GH}_2} - 0.1037 \dot{W}_{13\text{GH}_2}^2} \right)$$

$$(12) \quad N_{\text{S201}} = f \left(\frac{P_7 - P_8}{P_7} \right)$$

$$(13) \quad N_{\text{S251}} = f \left(\frac{P_8 - K_{\text{R26}} \dot{W}_8^2 - P_{14}}{P_8 - K_{\text{R26}} \dot{W}_8^2} \right)$$

$$K_{\text{R26}} = 0.1812 \text{ sec}^2/\text{lb in.}^2$$

$$\therefore N_{\text{S251}} = f \left(\frac{P_8 - 0.1812 \dot{W}_8^2 - P_{14}}{P_8 - 0.1812 \dot{W}_8^2} \right)$$

$$(14) \quad N_{\text{S454//460}} = f \left(\frac{P_{12\text{GH}_2} - K_{\text{R31}} \dot{W}_{12\text{GH}_2}^2 - P_{13\text{GH}_2}}{P_{12\text{GH}_2} - K_{\text{R31}} \dot{W}_{12\text{GH}_2}^2} \right)$$

$$K_{\text{R31}} = 0.0977 \text{ sec}^2/\text{lb in.}^2 \quad (\text{See "GH}_2 \text{ Line Lumps"})$$

$$\therefore N_{\text{S454//460}} = f \left(\frac{P_{12\text{GH}_2} - 0.0977 \dot{W}_{12\text{GH}_2}^2 - P_{13\text{GH}_2}}{P_{12\text{GH}_2} - 0.0977 \dot{W}_{12\text{GH}_2}^2} \right)$$

$$(15) \quad A_{eCDSV} = f(\theta_{CDSV})$$

$$(16) \quad a \quad \frac{\theta_{CDSV}}{\theta_{CDSVD}}(s) = \frac{1}{(0.02s^2 + 0.14s + 1)} \quad \text{NOTE: These equations are common for all coolants.}$$

$$(16) \quad b \quad \dot{\theta}_{CDSV} = \int_0^t \ddot{\theta}_{CDSV} dt$$

$$(16) \quad c \quad \theta_{CDSV} = \int_0^t \dot{\theta}_{CDSV} dt$$

$$(17) \quad a \quad \frac{L_{201}}{L_{201D}}(s) = \frac{1}{(1 + 0.35s)(1 + 0.40s)}$$

$$(17) \quad b \quad \dot{L}_{201} = \int_0^t \ddot{L}_{201} dt$$

$$(17) \quad c \quad L_{201} = \int_0^t \dot{L}_{201} dt$$

$$(18) \quad a \quad \frac{L_{251}}{L_{251D}}(s) = \frac{1}{(1 + 0.18s)(1 + 0.26s)}$$

$$(18) \quad b \quad \dot{L}_{251} = \int_0^t \ddot{L}_{251} dt$$

$$(18) \quad c \quad L_{251} = \int_0^t \dot{L}_{251} dt$$

$$(19) \quad A_{e201} = f(L_{201})$$

$$(20) \quad A_{251} = f(L_{251})$$

$$(21) \quad A_{e454} = f(L_{454})$$

$$(22) \quad A_{e460} = f(L_{460})$$

$$(23) \text{ a} \quad \frac{L_{454}}{L_{454D}} (s) = \frac{1}{(1 + 0.40S)(1 + 0.45S)}$$

$$(23) \text{ b} \quad \dot{L}_{454} = \int_0^t \ddot{L}_{454} dt$$

$$(23) \text{ c} \quad L_{454} = \int_0^t \dot{L}_{454} dt$$

$$(24) \text{ a} \quad \frac{L_{460}}{L_{460D}} (s) = \frac{1}{(1 + 0.40S)(1 + 0.45S)}$$

$$(24) \text{ b} \quad \dot{L}_{460} = \int_0^t \ddot{L}_{460} dt$$

$$(25) \text{ c} \quad L_{460} = \int_0^t \dot{L}_{460} dt$$

3.2.2.9.1.5 Summary of LH₂ Equations

$$(1) \text{ a } P_9 = P_9(0) = 1000 \text{ psia}$$

$$(1) \text{ b } T_4 = T_4(0) = 37^\circ\text{R}$$

$$(2) \quad \dot{W}_9 = .738 A_{e107} (P_9 - P_{10})^{1/2}$$

$$(3) \text{ a } \therefore \dot{P}_{10} = 126 (\dot{W}_9 - \dot{W}_{10})$$

$$(3) \text{ b } P_{10} = \int_0^t \dot{P}_{10} dt + P_{10} \text{ (I.C.)}$$

$$(4) \text{ a } \ddot{W}_{10} = 9.92 (P_{10} - 0.0054 \dot{W}_{10}^2 - P_{11})$$

$$(4) \text{ b } \dot{W}_{10} = \int_0^t \ddot{W}_{10} dt$$

$$(5) \text{ a } \therefore \dot{P}_{11} = 126 (\dot{W}_{10} - \dot{W}_{11})$$

$$(5) \text{ b } P_{11} = \int_0^t \dot{P}_{11} dt + P_{11} \text{ (I.C.)}$$

$$(6) \quad \dot{W}_{11} = 7.4 A_{e472} (P_{11} - P_{15})^{1/2}$$

$$(7) \text{ a } \therefore \dot{P}_{15} = 1036 (\dot{W}_{11} - \dot{W}_{14})$$

$$(7) \text{ b } P_{15} = \int_0^t \dot{P}_{15} dt + P_{15} \text{ (I.C.)}$$

$$(8) \quad \dot{W}_{14} = .75 (A_{e458} + A_{e459}) (P_{15} - P_{13} - 0.0036 \dot{W}_{14}^2)$$

$$(9) \text{ a } \therefore \dot{P}_{13\text{LH}_2} = 80 (\dot{W}_{14} - \dot{W}_{16})$$

$$(9) \text{ b } P_{13\text{LH}_2} = \int_0^t \dot{P}_{13\text{LH}_2} dt + P_{13} \text{ (I.C.)}$$

$$(10) \text{ a } \ddot{W}_{16} = 7.0 (P_{13LH_2} - P_{16LH_2} - 0.02345 \dot{W}_{16}^2)$$

$$(10) \text{ b } \dot{W}_{16} = \int_0^t \ddot{W}_{16} dt$$

$$(11) \text{ a } \dot{P}_{16LH_2} = 80 (\dot{W}_{16} - \dot{W}_{13})$$

$$(11) \text{ b } P_{16LH_2} = \int_0^t \dot{P}_{16LH_2} dt + P_{16LH_2} \text{ (I.C.)}$$

$$(12) \text{ a } \dot{W}_{13LH_2} = 1.167 A_{eCDSV} (P_{16LH_2} - P_{e3})^{1/2}$$

$$(12) \text{ b } \dot{W}_{13LH_2} \geq 0 \quad (\text{CDCHV})$$

$$(13) \quad L_{472} = \int_0^t \dot{L}_{472} dt$$

$$(14) \text{ a } \frac{L_{458}}{L_{458D}}(S) = \frac{1}{(1 + 0.70S)(1 + 0.60S)}$$

$$(14) \text{ b } \dot{L}_{458} = \int_0^t L_{458} dt$$

$$(14) \text{ c } L_{458} = \int_0^t \dot{L}_{458} dt$$

$$(15) \text{ a } \frac{L_{459}}{L_{459D}}(S) = \frac{1}{(1 + 0.70S)(1 + 0.60S)}$$

$$(15) \text{ b } \dot{L}_{459} = \int_0^t \ddot{L}_{459} dt$$

$$(15) \text{ c } L_{459} = \int_0^t \dot{L}_{459} dt$$

$$(16) \text{ a } \frac{L_{107}}{L_{107}}(S) = \frac{1}{(1 + 0.35S)(1 + 0.40S)}$$

$$(16) \text{ b } \dot{L}_{107} = \int_0^t \ddot{L}_{107} dt$$

$$(16) \text{ c } L_{107} = \int_0^t \dot{L}_{107} dt$$

$$(17) \text{ a } A_{e458} = f_1 (L_{458})$$

$$(17) \text{ b } A_{e459} = f_1 (L_{459})$$

$$(18) A_{e472} = f (L_{472})$$

$$(19) A_{eCDSV} = f (\Theta_{CDSV})$$

$$(20) \text{ a } \frac{\Theta_{CDSV}}{\dot{\Theta}_{CDSVD}}(S) = \frac{1}{(0.02S^2 + 0.14S + 1)S}$$

$$(20) \text{ b } \dot{\Theta}_{CDSV} = \int_0^t \ddot{\Theta}_{CDSV} dt$$

$$(20) \text{ c } \Theta_{CDSV} = \int_0^t \dot{\Theta}_{CDSV} dt$$

NOTE: These equations are common to all coolants.

3.2.2.9.1.6 LH₂ Equation Derivations

3.2.2.9.1.6.1 LH₂ Line Lumps - Fluid Resistances

For LH₂ @ 37°R @ 1000 PSIA

$$\begin{aligned}\rho_f &= 4.5 \text{ lb/ft}^3 \\ \nu &= 2.22 \times 10^{-6} \text{ ft}^2/\text{sec}\end{aligned}$$

$$\dot{W}_{\text{Max}} = 30 \text{ lb/sec}$$

$$N_{\text{Re}} = \frac{d \dot{W}}{\nu \rho_f A}$$

Where: d = Pipe Diameter (ft)
 ν = Fluid Viscosity (ft²/sec)
 ρ_f = Weight Density (lb/ft³)
 A = Area of Pipe (ft²)

For Lumps 1 and 2 (V-5002 to 50PCV472)-

Pipe is 6"-HV

$$\begin{aligned}\text{I.D.} &= 5.761 \text{ in.} = 0.48 \text{ ft} \\ \text{Area} &= 26.1 \text{ in.}^2 = 0.181 \text{ ft}^2 \\ \epsilon/d &= 0.00009 \text{ (} d = 5.761 \text{ in.}^2 \text{)}\end{aligned}$$

$$\therefore N_{\text{Re}1} = \frac{0.48 \times 30}{0.181 \times 4.5 \times 2.22 \times 10^{-6}} = 7.95 \times 10^6$$

$$\therefore f = 0.012 \text{ @ } \epsilon/d = 0.00009 \text{ (Assume constant over flow range)}$$

Thus-

$$\Delta P \text{ (lb/ft}^2\text{)} = f \left(\frac{\ell}{d}\right) \frac{\dot{W}^2}{2 \rho_f A^2 g} = K_{R11} \dot{W}^2 \quad \text{Where: } \ell = \text{Pipe Length (ft)} \\ f = \text{Friction Factor}$$

And -

$$K_{R11} = f (\ell/d) \frac{1}{2 \rho_f A^2 g}$$

$$K_{R11} = 1.2 \times 10^{-2} (84.5/0.48) \left(\frac{\text{sec}^2}{2 \times 4.5 \text{ lb} \times .0328 \times 32.2} \right) (\text{ft}^2/144 \text{ in.}^2)$$

$$K_{R11} = 1.50 \times 10^{-3} \frac{\text{sec}^2}{\text{in.}^2 \text{ lb}} \quad \text{Due to Line Only}$$

Also - For LH_2 Lumps 1 and 2 there are:

$$5 - 90^\circ \text{ Ells} \quad K = 0.67$$

$$1 - \text{Tee} \quad K_T = 1.75$$

$$1 - \text{Valve} \quad K_V = 0.25$$

$$\begin{aligned} K_{f15} &= \frac{\Sigma}{2g \rho_f A^2} K_f \\ &= \frac{5 (0.67) + 1.75 + 0.25 \text{ ft}^3 \text{ sec}^2 \text{ ft}^2}{(64.4) (4.5) (0.181^2) (144) \text{ ft lb ft}^4 \text{ in.}^2} \\ &= \frac{5.35}{.369} \frac{\text{sec}^2}{\text{lb in.}^2} \\ &= .0039 \text{ sec}^2/\text{lb in.}^2 \end{aligned}$$

$$\begin{aligned} K_{R1} &= K_{R11} + K_f \\ &= (1.50 \times 10^{-3}) + (3.90 \times 10^{-3}) \\ &= 5.40 \times 10^{-3} \end{aligned}$$

$$K_{R1} = 0.0054 \text{ sec}^2/\text{in.}^2 \text{ lb}$$

$$K_{R2} = K_{R31} + K_{f3}$$

Where: $K_{R21} = \text{Line } K_R \text{ Lump 3}$
 $K_{f3} = \text{Fitting K Lumps}$

Lump 3 has same line diameter as Lumps 1 and 2 ($\therefore N_{Re}$ is same, $\therefore f = 0.012$)

$$\begin{aligned} \therefore K_{R31} &= f \frac{L_3}{d} \frac{1}{2 \rho_f A_3^2 g} \\ &= 1.2 \times 10^{-2} (13/0.48) \left(\frac{1}{2 \times 4.5 \times (0.181)^2 \times 32.2 \times 144} \right) \end{aligned}$$

$$K_{R31} = 2.37 \times 10^{-4} \frac{\text{sec}^2}{\text{in.}^2 \text{ lb}}$$

Lump 3 has 1 - Ell, 2 - Tees, 2 - Valves

THUS-

$$K_{f3} = \frac{0.105}{144} [0.67 + (2 \times 1.75) + 2(.25)]$$

$$= 3.40 \times 10^{-3} \frac{\text{sec}^2}{\text{in.}^2 \text{ lb}}$$

$$\therefore K_{R2} = 0.0036 \frac{\text{sec}^2}{\text{in.}^2 \text{ lb}}$$

$$K_{R3} = K_{R41} + K_{f4}$$

Where: K_{R41} = Line K_R Lump 4
 J_{f4} = Fitting K Lump 4

Lump 4 has two sections of different diameters:

38 feet of 6 inch HV and 66.5 feet of 5 inch OD x .120 wall.

For 38 feet section, N_{Re} is same as Lumps 1, 2, and 3 and
 f is same as Lumps 1, 2, and 3.

$$\begin{aligned} \therefore K'_{R41} &= f \frac{L_{41}}{d} \frac{1}{2 \rho_f A_{41}^2 g} \\ &= 1.2 \times 10^{-2} (38/0.48) \left(\frac{1}{2 \times 4.5 \times (0.181)^2 \times 32.2 \times 144} \right) \\ K'_{R41} &= 6.94 \times 10^{-4} \frac{\text{sec}^2}{\text{in.}^2 \text{ lb}} \end{aligned}$$

For 38 foot section there are

- 5 - Tees
- 3 - 90° Ells
- 2 - 45° Ells
- 2 - Valves

Thus -

$$\begin{aligned} K'_{f4} &= \frac{0.105}{144} 5 (1.75) + 3(0.67) + 2(0.25) + 2 (0.40) \\ &= \frac{(0.105)(12.05)}{144} 8.8 \times 10^{-3} \end{aligned}$$

$$\begin{aligned}\text{For the 66.5 foot section of line to the CDSV - I.D.} &= 5 - (2)(.120) = \\ &= 4.76 \text{ in.}\end{aligned}$$

$$\begin{aligned}\text{Area} &= 22.7 \text{ in.}^2 \\ \epsilon/d &= 0.0001\end{aligned}$$

$$N_{Re4} = \frac{4.76 \times 30 \times 12}{2.22 \times 10^{-6} \times 4.5 \times 22.7} = \frac{1714}{226.8 \times 10^{-6}}$$

$$N_{Re4} = 7.57 \times 10^6$$

$$\therefore f = 0.012 @ \epsilon/d = 0.0001 \text{ (Assume constant over flow range)}$$

Thus -

$$\Delta P(\text{lb/ft}^2) = f_4 \left(\ell_4/d_4 \right) \frac{\dot{W}^2}{2 \rho_f A^2 g} = K'_{R41} \dot{W}^2$$

$$\therefore K''_{R41} = 1.2 \times 10^{-2} (66.5/.397 \text{ ft.}) \frac{\text{ft ft}^3 \text{ sec}^2 \text{ ft}^2}{2 \times 4.5 \text{ lb} \times (.157^2 \text{ ft}^4) 32.2 \text{ ft} 144 \text{ in.}^2}$$

$$K''_{R41} = 1.96 \times 10^{-3} (\text{sec}^2/\text{lb in.}^2)$$

$$\begin{aligned}\text{AND } K_{R41} &= K'_{R41} + K''_{R41} = 6.94 \times 10^{-4} + 1.96 \times 10^{-3} \\ &= 2.65 \times 10^{-3} (\text{sec}^2/\text{lb in.}^2)\end{aligned}$$

For the 66.5 foot section there are:

2 - 90° Ells

1 - Tee

3 - Bellows

1 - CHV

1 - Valve

$$K_{f4}'' = \frac{2(0.67) + (1.75) + 3(2.0) + (3) + (.25) \text{ sec}^2 \text{ ft}^3 \text{ ft}^2}{2g \rho_f \times A^2 \text{ ft lb ft}^4 144 \text{ in.}^2}$$

$$= \frac{(1.3 + 1.75 + 6 + 3 + .25)}{(144) 64.4 \times 4.5 \times (.0246)} = \frac{12.3}{1026}$$

$$= 1.20 \times 10^{-2} (\text{sec}^2/\text{lb in.}^2)$$

$$\therefore K_{f4} = K_{f4}' + K_{f4}'' = 8.8 \times 10^{-3} + 12.0 \times 10^{-3} = 20.8 \times 10^{-3}$$

$$\therefore K_{R3} = (2.65 + 20.8) \times 10^{-3} = 2.34 \times 10^{-2} (\text{sec}^2/\text{lb in.}^2)$$

3.2.2.9.1.6.2 LH₂ Physical Equations

$$(1) \text{ a } P_9 = P_9(0) = 1000 \text{ PSIA}$$

$$(1) \text{ b } T_4 = T_4(0) = 37^\circ\text{R}$$

$$(2) \quad \dot{W}_9 = K_1 A_{e107} (P_9 - P_{10})^{1/2}$$

$$\text{When the valve is full open } C_v = 130 \frac{\text{Gal}}{\text{Min}} \text{ H}_2\text{O}$$

$$@ \Delta P = 1 \text{ PSI}$$

$$A_{e107} = 29.00 \text{ in.}^2$$

$$\begin{aligned} \therefore K_1 &= \frac{\dot{W}_9 \text{ Max}}{A_{e107} \text{ Max}} = \dot{W}_9 \text{ Max} = \frac{C_v}{37.6} \sqrt{.0446 \Delta P \rho_f} \\ &= \frac{21.4 \text{ lb/Sec}}{29.00 \text{ in.}^2} (\text{lb/in.}^2)^{-1/2} = \frac{580}{37.6} [0.446 (1) 4.5]^{1/2} \end{aligned}$$

$$K_1 = 0.738 \frac{\text{lb}^{1/2}}{\text{in. sec}} = 21.4 \text{ lb/sec}$$

Thus -

$$\dot{W}_9 = 0.738 \frac{\text{lb}^{1/2}}{\text{in. sec}} A_{e107} (P_9 - P_{10})^{1/2}$$

$$(3) \text{ a } \dot{P}_{10} = K_2 (\dot{W}_9 - \dot{W}_{10})$$

$$K_2 = \frac{\beta}{K_{pf}} \frac{1}{V_{o1_1}} = \frac{6.59 \times 10^6}{2(15.13) \times .1728 \text{ in.}^2} = 126 \text{ in.}^{-2}$$

$$\therefore \dot{P}_{10} = 126 (\dot{W}_9 - \dot{W}_{10})$$

$$(3)b \quad P_{10} = \int_0^t \dot{P}_{10} dt + P_{10} (I.C.)$$

$$(4)a \quad \ddot{W}_{10} = K_3 (P_{10} - K_{R4} \dot{W}_{10}^2 - P_{11})$$

$$K_3 = \frac{A_1 g}{l_1} = \frac{0.181 \times 32.2 \times 144 \text{ in.}^2}{84.5 \text{ sec}^2} = 9.92 \frac{\text{in.}^2}{\text{sec}^2}$$

$$K_{R4} = K_{R1} \text{ (Refer to "LH}_2 \text{ Line Lumps")} = 0.0054 \frac{\text{sec}^2}{\text{in.}^2_{1b}}$$

Thus -

$$\ddot{W}_{10} = 9.92 \frac{\text{in.}^2}{\text{sec}^2} (P_{10} - 0.0054 \frac{\text{sec}^2}{\text{in.}^2_{1b}} \dot{W}_{10}^2 - P_{11})$$

$$(4)b \quad \ddot{W}_{10} = \int_0^t \ddot{W}_{10} dt$$

$$(5)a \quad \dot{P}_{11} = K_5 (\dot{W}_{10} - \dot{W}_{11})$$

$$K_5 = K_2 = 126 \text{ in.}^{-2}$$

$$\therefore \dot{P}_{11} = 126 \text{ in.}^{-2} (\dot{W}_{10} - \dot{W}_{11})$$

$$(5)b \quad P_{11} = \int_0^t \dot{P}_{11} dt + P_{11} (I.C.)$$

$$(6)a \quad \dot{W}_{11} = K_6 A_{e472} (P_{11} - P_{15})^{1/2}$$

When Valve is Full Open: $C_V = 130 \text{ Gal/Min}$
 $\Delta P = 1 \text{ PSI}$
 $A_{e472} = 6.5 \text{ in.}^2$

$$\begin{aligned} \therefore K_1 &= \frac{\dot{W}_{11 \text{ Max}}}{A_{e472 \text{ Max}}} & \dot{W}_{11 \text{ Max}} &= \frac{C_V}{37.98} = \sqrt{0.446 \Delta P \rho_f} \\ &= \frac{48 \text{ lb/sec}}{6.5 \text{ in.}^2} \frac{\text{lb}}{\text{in.}^2}^{-1/2} & &= 48 \text{ lb/sec} \\ &= 7.4 (\text{lb})^{1/2} / \text{in. sec} \end{aligned}$$

$$\text{Thus} - \dot{W}_{11} = 7.4 \text{ lb}^{1/2} / \text{in. sec} A_{e472} (P_{11} - P_{15})^{1/2}$$

$$(7)a \quad \dot{P}_{15} = K_7 (\dot{W}_{11} - \dot{W}_{14})$$

$$K_7 = \frac{6.59 \times 10^6}{3.68 \times 1728 \text{ in.}^2} = 1036 \text{ in.}^{-2}$$

$$\therefore \dot{P}_{15} = 1036 \text{ in.}^{-2} (\dot{W}_{11} - \dot{W}_{14})$$

$$(7)b \quad P_{15} = \int_0^t \dot{P}_{15} dt + P_{15} \text{ (I.C.)}$$

$$(8) \quad \dot{W}_{14} = K_{10} (A_{e458} + A_{e459}) (P_{15} - P_{13} - K_{R81} \dot{W}_{14}^2)$$

$$\text{When both valves are open: } \Sigma C_V = 2(625) = 1250 \text{ gal/min}$$

$$\Delta P = 1 \text{ psi}$$

$$\Sigma A_e = 62.44 \text{ in.}^2$$

$$K_{10} = \frac{\dot{W}_{14 \text{ max}}}{A_e}$$

$$= \frac{46.75}{62.44}$$

$$\dot{W}_{14 \text{ max}} = \frac{C_V}{37.98} \sqrt{0.446 \Delta P \rho_f}$$

$$K_{10} = 0.75 \frac{\text{lb}^{1/2}}{\text{in. sec}} = \frac{1250}{37.98} (1.415) = 46.75 \text{ lb/sec}$$

$$K_{R81} = K_{R2} \text{ (Refer to "LH}_2 \text{ Line Lumps")} = 0.0036 \frac{\text{sec}^2}{\text{in.}^2 \text{ lb}}$$

Thus -

$$\dot{W}_{14} = 0.75 \frac{\text{lb}^{1/2}}{\text{in. sec}} (A_{e458} + A_{e459}) (P_{15} - P_{13} - 0.0036 \dot{W}_{14}^2)$$

$$(9)a \quad \dot{P}_{13LH_2} = K_{11} (\dot{W}_{14} - \dot{W}_{16})$$

$$K_{11} = \frac{6.59 \times 10^6}{2(23.86) \times 1728 \text{ in.}^2} = 80 \text{ in.}^{-2}$$

$$\therefore \dot{P}_{13LH_2} = 80 \text{ in.}^{-2} (\dot{W}_{14} - \dot{W}_{16})$$

$$(9)b \quad \dot{P}_{13LH_2} = \int_0^t \dot{P}_{13LH_2} dt + P_{13} \text{ (I.C.)}$$

$$(10)a \quad \ddot{W}_{16} = \frac{A_4 g}{l_4} (P_{13LH_2} - P_{16LH_2} - K_{R3} \dot{W}_{16}^2) =$$

$$\frac{A_4 g}{l_4} = \frac{22.7 \text{ in.}^2 \cdot 32.2}{104.5 \text{ sec}^2} = 7.0 \text{ in.}^2/\text{sec}^2$$

$$K_{R3} = 0.0234 \frac{\text{sec}^2}{\text{lb in.}} \text{ (see "LH}_2 \text{ Line Lumps")}$$

Thus -

$$\ddot{W}_{16} = 7.0 \text{ in.}^2/\text{sec}^2 (P_{13LH_2} - P_{16LH_2} - 0.0234 \frac{\text{sec}^2}{\text{lb in.}} \dot{W}_{16}^2)$$

$$(10)b \quad \dot{W}_{16} = \int_0^t \ddot{W}_{16} dt$$

$$(11)a \quad \dot{P}_{16LH_2} = K_{11} (\dot{W}_{16} - \dot{W}_{13})$$

$$\dot{P}_{16LH_2} = 80 \text{ in.}^{-2} (\dot{W}_{16} - \dot{W}_{13})$$

$$(11)b \quad P_{16LH_2} = \int_0^t \dot{P}_{16LH_2} dt + P_{16LH_2} \text{ (I.C.)}$$

$$(12)a \quad \dot{W}_{13LH_2} = K_{12} A_{eCDSV} (P_{16LH_2} - P_{e3})^{1/2}$$

$$\text{When the CDSV is fully open: } \dot{W}_{13LH_2 \text{ Max}} = 35 \text{ lb/sec}$$

$$\therefore K_{12} = \frac{35 \text{ lb/sec}}{30 \text{ in.}^2} \left(\frac{1 \text{ lb}}{\text{in.}^2} \right)^{-1/2} \quad \Delta P_{\text{Max}} = 1 \text{ psi}$$

$$= 1.167 \frac{\text{lb}}{\text{in. sec}}^{1/2} \quad A_{eCDSV} \approx 30 \text{ in.}^2$$

Thus -

$$\dot{W}_{13LH_2} = 1.167 \frac{\text{lb}^{1/2}}{\text{in. sec}} A_{eCDSV} (P_{16LH_2} - P_{e3})^{1/2}$$

$$(12)b \quad \dot{W}_{13LH_2} \geq 0 \quad (\text{CDCHV})$$

$$(13) \quad L_{472} = \int_0^t \dot{L}_{472} dt$$

$$(14)a \quad \frac{L_{458}}{L_{458D}}(s) = \frac{1}{(1 + 0.70S)(1 + 0.60S)}$$

$$(14)b \quad \dot{L}_{458} = \int_0^t \ddot{L}_{458} dt$$

$$(14)c \quad L_{458} = \int_0^t \dot{L}_{458} dt$$

$$(15)a \quad \frac{L_{459}}{L_{459D}}(s) = \frac{1}{(1 + 0.70S)(1 + 0.60S)}$$

$$(15)b \quad \dot{L}_{459} = \int_0^t \ddot{L}_{459} dt$$

$$(15)c \quad L_{459} = \int_0^t \dot{L}_{459} dt$$

$$(16)a \quad \frac{L_{107}}{L_{107D}}(s) = \frac{1}{(1 + 0.35s)(1 + 0.40s)}$$

$$(16)b \quad \dot{L}_{107} = \int_0^t \ddot{L}_{107} dt$$

$$(16)c \quad L_{107} = \int_0^t \dot{L}_{107} dt$$

$$(17)a \quad A_{e458} = f_1(L_{458})$$

$$(17)b \quad A_{e459} = f_1(L_{459})$$

$$(18) \quad A_{e472} = f(L_{472})$$

$$(19) \quad A_{eCDSV} = f(\Theta_{CDSV})$$

$$(20)a \quad \frac{\Theta_{CDSV}}{\Theta_{CDSVD}}(s) = \frac{1}{(0.02s^2 + 0.14s + 1)}$$

$$(20)b \quad \Theta_{CDSV} = \int_0^t \ddot{\Theta}_{CDSV} dt$$

$$(20)c \quad \Theta_{CDSV} = \int_0^t \dot{\Theta}_{CDSV} dt$$

$$(21) \quad A_{e107} = f(L_{107})$$

3.2.2.9.1.7 Summary of LN₂ Equations

$$(1)a \quad P_1 = P_1(0) = 250 \text{ psia}$$

$$(1)b \quad T_1 = T_1(0) = 202^\circ\text{R}$$

$$(2)a \quad \therefore \ddot{W}_1 = 3.34 (250 - 0.00194 W_1^2 - P_2)$$

$$(2)b \quad \dot{W}_1 = \int \ddot{W}_1 dt$$

$$(3)a \quad \therefore \dot{P}_2 = 20.5 (\dot{W}_1 - \dot{W}_2)$$

$$(3)b \quad P_2 = \int \dot{P}_2 dt + P_2 \text{ (I.C.)}$$

$$(4) \quad \therefore \dot{W}_2 = 2.175 A_{e517} (P_2 - P_3)^{1/2}$$

$$(5)a \quad \therefore \dot{P}_3 = 42.2 (\dot{W}_2 - \dot{W}_3)$$

$$(5)b \quad P_3 = \int \dot{P}_3 dt + P_3 \text{ (I.C.)}$$

$$(6) \quad \therefore \dot{W}_3 = 2.18 A_{e545} (P_3 - P_{13LN_2} - 0.00126 \dot{W}_3^2)^{1/2}$$

$$(7)a \quad \therefore \dot{P}_{13LN_2} = 80 (\dot{W}_3 - \dot{W}_{16})$$

$$(7)b \quad P_{13LN_2} = \int \dot{P}_{13LN_2} dt + P_{13} \text{ (I.C.)}$$

$$(8)a \quad \ddot{\dot{W}}_{16LN_2} = 40.1 (P_{13} - 0.0093 \dot{W}_{16LN_2}^2 - P_{16LN_2})$$

$$(8)b \quad \dot{W}_{16LN_2} = \int \ddot{\dot{W}}_{16LN_2} dt$$

$$(9)a \quad \dot{P}_{16LN_2} = 80 (\dot{W}_{16LN_2} - \dot{W}_{13})$$

$$(9)b \quad P_{16LN_2} = \int \dot{P}_{16LN_2} dt + P_{16LN_2} \text{ (I.C.)}$$

$$(10)a \quad \dot{W}_{13LN_2} = 3.0 A_{eCDSV} (P_{16LN_2} - P_{e3})^{1/2}$$

$$(10)b \quad \dot{W}_{13LN_2} \geq 0 \quad (\text{Since CDSV is immediately followed by CDSHV})$$

$$(11) \quad A_{eCDSV} = f(\theta_{CDSV})$$

$$(12)a \quad \frac{\theta_{CDSV}}{\theta_{CDSVD}}(S) = \frac{1}{(0.02S^2 + 0.14S + 1)} \quad \text{NOTE: These equations are common to all coolants}$$

$$(12)b \quad \dot{\theta}_{CDSV} = \int_0^t \ddot{\theta}_{CDSV} dt$$

$$(12)c \quad \theta_{CDSV} = \int_0^t \dot{\theta}_{CDSV} dt$$

$$(13)a \quad \frac{L_{517}}{L_{517D}}(S) = \frac{1}{(1 + 0.30S)(1 + 0.42S)}$$

$$(13)b \quad \dot{L}_{517} = \int_0^t \ddot{L}_{517} dt$$

$$(13) c \quad L_{517} = \int_0^t \dot{L}_{517} dt$$

$$(14) a \quad \frac{L_{545}}{L_{545D}}(s) = \frac{1}{(1 + 0.70s)(1 + 0.60s)}$$

$$(14) b \quad \dot{L}_{545} = \int_0^t \ddot{L}_{545} dt$$

$$(14) c \quad L_{545} = \int_0^t \dot{L}_{545} dt$$

$$(15) \quad A_{e517} = f(L_{517})$$

$$(16) \quad A_{e545} = f(L_{545})$$

For LN_2 @ 202°R @ 250 psia

$$\rho_f = 37.4 \text{ lb/ft}^3$$

$$v = 1.08 \times 10^{-6} \text{ ft}^2/\text{sec}$$

$$\dot{W}_{\text{Max}} = 85 \text{ lb/sec}$$

$$N_{\text{RC}} = \frac{d \dot{W}}{v \rho_f A}$$

For Lumps 1, 2, 3: $d = 0.48 \text{ ft}$, $A = 0.181 \text{ ft}^2$, $\epsilon/d = 0.0001$

$$N_{\text{Re1}} = N_{\text{Re2}} = N_{\text{Re3}} = \frac{0.48 \text{ ft} \times 85}{1.08 \times 10^{-6} \times 37 \times .181} = 5.64 \times 10^6$$

$$f_1 = f_2 = f_3 = 0.012$$

Thus -

$$\Delta P(\text{lb/ft}^2) = f (\ell/d) \frac{\dot{W}^2}{2 \rho_f A^2 g} = K'_{\text{R15}} \dot{W}^2$$

$$K'_{\text{R15}} = f (\ell/d) \frac{1}{2 \rho_f A^2 g}$$

$$= \frac{1.2 \times 10^{-2} (251) \text{ sec}^2}{2 (0.48) (37.44 \text{ lb}) (.0328) 32.2 \text{ 144 in.}^2}$$

$$= 5.51 \times 10^{-4} \frac{\text{sec}^2}{\text{lb in.}^2}$$

Where $K_{\text{R15}} = K'_{\text{R15}} + K_{\text{f15}}$

For Lump 1 there are: 5 - 90°

1 - 45°

4 - (3:1) (K = 2.0)

6 - T

3 - V

$$\begin{aligned}
 K_{f15} &= \frac{\sum K_f}{2 \rho_f g A^2} \\
 &= \frac{5(0.67) + 1(0.40) + 4(2.0) + 6(1.75) + 3(0.25)}{2(37.44)(32.2)(0.0328)(144)} \frac{\text{ft}^3 \text{sec}^2}{\text{ft lb}} \text{ft}^4 \frac{\text{ft}^2}{\text{in.}^2} \\
 &= \frac{3.35 + 0.04 + 8.0 + 10.50 + 0.75}{(37.44)(64.4)(0.0328)(144)} = \frac{15.80}{11,388} \\
 &= 13.9 \times 10^{-4} \frac{\text{sec}^2}{\text{lb in.}^2} \\
 K_{R15} &= 5.51 \times 10^{-4} + 13.9 \times 10^{-4} = 19.41 \times 10^{-4} \frac{\text{sec}^2}{\text{lb in.}^2} \\
 &= 0.00194 \frac{\text{sec}^2}{\text{lb in.}^2}
 \end{aligned}$$

For Lump 2 -

$$f = 0.012$$

$$K_{R21} = K_{R21}^1 + K_{f21}$$

$$\begin{aligned} K_{R21}^1 &= f(l/d) \frac{1}{2 \rho_f A^2 g} \\ &= \frac{(1.2 \times 10^{-2})(122.55 \text{ ft}) \text{ ft}^3 \text{ sec}^2 \text{ ft}^2}{2(0.48 \text{ ft}) (37.44 \text{ lb})(0.0328 \text{ ft}^4)(32.2 \text{ ft})(144) \text{ in.}^2} \\ &= 2.69 \times 10^{-4} \frac{\text{sec}^2}{\text{lb in.}^2} \end{aligned}$$

$$K_{f21} = \frac{\sum K_f}{2 \rho_f g A^2}$$

For Lump 2 there are: 6 - 90°

1 - V

1 - CHV

2 - (K = 2.0)

$$\begin{aligned} K_{f21} &= \frac{6(.67) + 1(.25) + 1(3.0) + 2(2.0)}{2(37.44)(32.2)(0.0328)(144)} \frac{\text{sec}^2}{\text{lb in.}^2} \\ &= \frac{11.27}{(64.4)(37.44)(.0328)(144)} \\ &= 9.90 \times 10^{-4} \frac{\text{sec}^2}{\text{lb in.}^2} \end{aligned}$$

$$K_{R21} = (2.69 + 9.90) \times 10^{-4} = 12.6 \times 10^{-4}$$

$$= .00126 \frac{\text{sec}^2}{\text{lb in.}^2}$$

For Lumps 3 and 4 -

$$N_{Re3} = 5.64 \times 10^6 \quad \therefore f_3 = 0.012$$

$$d_4 = 0.476 \text{ ft.}$$

$$A_4 = 0.125 \text{ ft.}^2$$

$$\begin{aligned} \therefore N_{Re4} &= \frac{0.476 \text{ ft. } 85 \text{ lb/sec}}{(37.44 \text{ lb/ft.}^3)(1.08 \times 10^{-6} \text{ ft.}^2/\text{sec})(0.125 \text{ ft.}^2)} \\ &= 6.41 \times 10^7 \quad \therefore f_4 = 0.012 \end{aligned}$$

$$K_{R24} = K_{R24}^1{}_3 + K_{R24}^1{}_4 + K_{f24}^1{}_3 + K_{f24}^1{}_4$$

$$\begin{aligned} K_{R24}^1{}_3 &= f_3 \left(\ell_3/d_3 \right) \frac{1}{2 \rho_f A_3^2 g} \\ &= \frac{(1.2 \times 10^{-2} \times 26.75 \text{ ft. } \text{ft.}^2)}{(0.48 \text{ ft.})(2)(37.44 \text{ lb/ft.}^3)(0.0328 \text{ ft.}^4)(32.2 \text{ ft./sec}^2)(144 \text{ in.}^2)} \\ &= 5.87 \times 10^{-5} \frac{\text{sec}^2}{\text{lb in.}^2} \end{aligned}$$

$$\begin{aligned} K_{R24}^1{}_4 &= \frac{(1.2 \times 10^{-2})(66 \text{ ft.})}{(0.476 \text{ ft.})(2)(37.44 \text{ lb/ft.}^3)(0.0156 \text{ ft.}^4)(32.2 \text{ ft./sec}^2)(144 \text{ in.}^2)} \\ &= 3.07 \times 10^{-4} \frac{\text{sec}^2}{\text{lb in.}^2} \end{aligned}$$

For Lump 3 there are: 6 - 90°

5 - T

1 - CHV

$$\begin{aligned}\therefore K_{f24 \quad 3} &= \frac{6(0.67) + (1.75) + (3.0)}{2(37.44)(0.0328)(32.2)(144)} \\ &= 1.38 \times 10^{-3} \frac{\text{sec}^2}{\text{lb in.}^2}\end{aligned}$$

For Lump 4 there are: 4 - 90°

2 - 45°

3 - T

3 - Bellows

1 - V

1 - CHV

$$\begin{aligned}K_{f24 \quad 4} &= \frac{4(0.67) + 2(0.40) + 3(1.75) + 1(3.0) + 3(2.5) + (.25)}{2(37.44)(0.0156)(32.2)(144)} \\ &= 7.56 \times 10^{-3} \frac{\text{sec}^2}{\text{lb in.}^2}\end{aligned}$$

$$\begin{aligned}K_{R24} &= (0.00587 + .0307 + 0.138 + 0.756) \times 10^{-2} \frac{\text{sec}^2}{\text{lb in.}^2} \\ &= 9.30 \times 10^{-3} \frac{\text{sec}^2}{\text{lb in.}^2}\end{aligned}$$

3.2.2.9.1.8 LN₂ Physical Equations

$$(1) \text{ a } P_1 = P_1(0) = 250 \text{ psia}$$

$$(1) \text{ b } T_1 = T_1(0) = 202^\circ\text{R}$$

$$(2) \text{ a } \ddot{W}_1 = K_{14} (250 - K_{R15} \dot{W}_1^2 - P_2)$$

$$\begin{aligned} K_{14} &= \frac{A_1 g}{\ell_1} = \frac{0.181 \text{ ft}^2 \times 32.2 \text{ ft} \times 144 \text{ in.}^2}{251 \text{ ft sec}^2 \text{ ft}^2} \\ &= 3.34 \text{ in.}^2/\text{sec}^2 \end{aligned}$$

$$K_{R15} = 0.00194 \frac{\text{sec}^2}{\text{lb in.}^2}$$

$$\therefore \ddot{W}_1 = 3.34 (250 - 0.00194 \dot{W}_1^2 - P_2)$$

$$(2) \text{ b } \dot{W}_1 = \int_0^t \ddot{W}_1 dt$$

$$(3) \text{ a } \dot{P}_2 = K_{16} (\dot{W}_1 - \dot{W}_2)$$

$$\begin{aligned} K_{16} &= \frac{\beta}{K\rho_f} \frac{1}{Vol_1} = \frac{1.64 \times 10^6 \text{ in. ft}^3}{46.5 \text{ ft}^3 \times 1728 \text{ in.}^3} \\ &= 20.5 \text{ in.}^{-2} \end{aligned}$$

$$\therefore P_2 = 20.5 (\dot{W}_1 - \dot{W}_2)$$

$$(3) \quad b \quad P_2 = \int_0^t \dot{P}_2 dt + P_2 \text{ (I.C.)}$$

$$(4) \quad \dot{W}_2 = K_{517} A_{e517} (P_2 - P_3)^{1/2}$$

When the Valve is Full Open -

CV = 125 GPM

@ $\Delta P = 1$ psi

$$K_{517} = \frac{W_2 @ \Delta P = 1}{A_{e517 \text{ Max}} (\Delta P)^{1/2}}$$

$$A_{e517 \text{ Max}} = 625 \text{ in.}^2$$

$$= \frac{13.58 \text{ lb/sec}}{6.25 \text{ in.}^2} \left(\frac{1 \text{ lb}}{\text{in.}^2} \right)^{-1/2}$$

$$W_2 = CV/37.6 \sqrt{0.446 \Delta P \rho_f}$$

@ $\Delta P = 1$

$$= 2.175 \frac{\text{lb}^{1/2}}{\text{in. sec}}$$

$$= 125/37.6 \sqrt{0.446(1)(37.44)}$$

$$= 13.58 \text{ lb/sec}$$

$$\therefore \dot{W}_2 = 2.175 A_{e517} (P_2 - P_3)^{1/2}$$

$$(5) \quad a \quad \dot{P}_3 = K_{17} (\dot{W}_2 - \dot{W}_3)$$

$$K_{17} = \frac{\beta}{K_{of}} \frac{1}{\text{Vol}_2} = \frac{1.647 \times 10^6 \text{ in. ft}^3}{22.6 \text{ ft}^3 \times 1728 \text{ in.}^3}$$

$$= 42.2 \text{ in.}^{-2}$$

$$\therefore \dot{P}_3 = 42.2 (\dot{W}_2 - \dot{W}_3)$$

$$(5) \quad b \quad P_3 = \int_0^t \dot{P}_3 dt + P_3 \text{ (I.C.)}$$

$$(6) \quad \dot{W}_3 = K_{20} A_{e545} (P_3 - P_{13LN_2} - K_{R21} \dot{W}_3^2)^{1/2}$$

$$K_{R21} = 1.26 \times 10^{-3} \frac{\text{sec}^2}{\text{lb in.}^2} \quad \text{When Valve is full open:}$$

$$CV = 625 \text{ GPM @ } \Delta P = 1 \text{ psia}$$

$$K_{20} = \frac{\dot{W}_3}{A_{e517 \text{ Max}} (\Delta P)^{1/2}}$$

$$A_{e545} = 31.22 \text{ in.}^2$$

$$\dot{W}_2 = CV/37.6 (0.446 P \rho_f)^{1/2}$$

$$= \frac{68.2 \text{ lb/sec lb}^{1/2}}{31.22 \text{ in.}^2 \text{ in.}} = 2.18$$

$$@ \Delta P = 1$$

$$= 625/37.6 (0.446(1)(37.44))^{1/2}$$

$$= 68.2 \text{ lb/sec}$$

$$\therefore \dot{W}_3 = 2.18 A_{e545} (P_3 - P_{13LN_2} - 0.00126 \dot{W}_3^2)^{1/2}$$

$$(7) \text{ a } \dot{P}_{13LN_2} = K_{22} (\dot{W}_3 - \dot{W}_{16LN_2})$$

$$K_{22} = \frac{\beta}{k_f^{\rho}} \cdot \frac{1}{Vol_3}$$

$$Vol_3 = 1/2 \text{ Vol of Common Manifold}$$

$$= \frac{(1.647 \times 10^6)(2) \text{ in. ft}^3}{(23.86)(1728) \text{ ft}^3 \text{ in.}^3}$$

$$= \frac{3.294 \times 10^6 \text{ in.}^{-2}}{4.123 \times 10^4} = 79.9 \text{ in.}^{-2}$$

$$\therefore \dot{P}_{13LN_2} = 79.9 (\dot{W}_3 - \dot{W}_{16LN_2})$$

$$(7) \text{ b } P_{13LN_2} = \int_0^t \dot{P}_{13LN_2} dt + P_{13} \text{ (I.C.)}$$

$$(8) \text{ a } \ddot{W}_{16LN_2} = K_{18} (P_{13LN_2} - K_{R24} \dot{W}_{LN_2}^2 - P_{16LN_2})$$

$$K_{18} = g \left(\frac{A_1}{\ell_1} + \frac{A_2}{\ell_2} \right) = \frac{32.2 \text{ ft}}{\text{sec}^2} \left(\frac{0.181 \text{ ft}^2}{26.75 \text{ ft}} + \frac{0.125 \text{ ft}^2}{66 \text{ ft}} \right) \left(\frac{144 \text{ in.}^2}{\text{ft}^2} \right)$$

$$= (32.2) (.008670(144)) \frac{\text{in.}^2}{\text{sec}^2} = 40.2 \frac{\text{in.}^2}{\text{sec}^2}$$

$$\therefore \ddot{W}_{16LN_2} = 40.2 (P_{13} - .0093 \dot{W}_{16LN_2}^2 - P_{16LN_2})$$

$$(8) \text{ b } \dot{W}_{16LN_2} = \int_0^c \ddot{W}_{16LN_2} dt$$

$$(9) \text{ a } \dot{P}_{16LN_2} = K_{19} (\dot{W}_{16LN_2} - \dot{W}_{13}) \quad K_{19} = K_{22} = 79.9 \text{ in.}^{-2}$$

$$\therefore \dot{P}_{16LN_2} = 79.9 (\dot{W}_{16LN_2} - \dot{W}_{13})$$

$$(9) \text{ b } P_{16LN_2} = \int_0^t \dot{P}_{16LN_2} dt + P_{16LN_2} \text{ (I.C.)}$$

$$(10) \text{ a } \dot{W}_{13LN_2} = K_{23} A_{eCDSV} (P_{16LN_2} - P_{e3})^{1/2}$$

When CDSV is full open -

$$\dot{W}_{13LN_2}^{\text{Max}} = 90 \text{ lb/sec}$$

$$\therefore K_{23} = \frac{90 \text{ lb}}{30 \text{ in.}^2} \left(\frac{1 \text{ lb}}{\text{in.}^2} \right)^{1/2}$$

$$\Delta P = 1 \text{ psia}$$

$$= 3.0 \frac{\text{lb}^{1/2}}{\text{in. sec}}$$

$$A_{eCDSV} \approx 30 \text{ in.}^2$$

$$\therefore \dot{W}_{13LN_2} = 3.0 A_{eCDSV} (P_{16LN_2} - P_{e3})^{1/2}$$

$$(10) \text{ b } \dot{W}_{13LN_2} \geq \text{ Since CDSV is immediately followed by CDCHV.}$$

$$(11) \quad A_{eCDSV} = f(\theta_{CDSV})$$

$$(12) \text{ a } \frac{\theta_{CDSV}}{\theta_{CDSVD}}(s) = \frac{1}{(0.02s^2 + 0.14s + 1)}$$

$$(12) \text{ b } \dot{\theta}_{CDSV} = \int_0^t \ddot{\theta}_{CDSV} dt$$

NOTE: These are common equations for all coolants.

$$(12) \text{ c } \theta_{CDSV} = \int_0^t \dot{\theta}_{CDSV} dt$$

$$(13) \text{ a } \frac{L_{517}}{L_{517D}}(s) = \frac{1}{(1 + 0.30S)(1 + 0.42S)}$$

$$(13) \text{ b } \dot{L}_{517} = \int_0^t \ddot{L}_{517} dt$$

$$(13) \text{ c } L_{517} = \int_0^t \dot{L}_{517} dt$$

$$(14) \text{ a } \frac{L_{545}}{L_{545D}}(2) = \frac{1}{(1 + 0.70S)(1 + 0.60S)}$$

$$(14) \text{ b } \dot{L}_{545} = \int_0^t \ddot{L}_{545} dt$$

$$(14) \text{ c } L_{545} = \int_0^t \dot{L}_{545} dt$$

$$(15) \quad A_{e517} = f(L_{517})$$

$$(16) \quad A_{e545} = f(L_{545})$$

3.2.2.9.2 LOGIC EQUATIONS - COOLDOWN

Refer to AGC Drawing 1114289 and EAL Drawing 04.00551

3.2.2.9.2.1 COOLDOWN NETWORK EQUATIONS

<u>LOGIC EQN NO.</u>	<u>FUNCTION*</u>	<u>BOOLEAN DRIVING FUNCTION</u>
1	K1	$471 \cdot \text{Reset}'$
2	K4	$(107 \cdot \text{Reset}') \cdot \left\{ \left[P_2 > P_3 \right] \cdot \left[517 \cdot 545 \cdot \text{Reset}' \right] \right. \\ \left. \left[(458 + 459) \cdot \left\{ 472 \cdot (107 \cdot \text{Reset}') \right\} \right] \right\}$
3	K5	$201 \cdot \text{Reset}'$
4	K6	FF 08B Set
5	K7	$(471 \cdot \text{Reset}') + \text{FF 08A Set}$
6	K8	$(107 \cdot \text{Reset}') + \text{FF 08D Set}$
7	K9	FF 11A Set
8	K10	$\left[472 \cdot (107 \cdot \text{Reset}') \right] + \text{FF 08C Set}$
9	K11	FF 39B Set
10	K12	FF 39A Set
11	K13	FF 11C Set
12	K14	FF 11B Set
13	K15	CSV
14	K16	$\left[472 \cdot (107 \cdot \text{Reset}') \right] \cdot \left\{ \left[P_2 > P_3 \right] \cdot \left[517 \cdot 545 \cdot \text{Reset}' \right] \right. \\ \left. \cdot \left[(458 + 459) \cdot \left\{ 472 \cdot (107 \cdot \text{Reset}') \right\} \right] \right\}$
15	K18	517
16	K20	$(P_{13} < P_{15}) \cdot 472' \cdot (458 + 459)$
17	K21	$472 \cdot (107 \cdot \text{Reset}')$
18	K22	$545 \cdot 517'$
19	K24	$(251 \cdot \text{Reset}') \cdot (201 \cdot \text{Reset}')$

<u>LOGIC EQN NO.</u>	<u>FUNCTION*</u>	<u>BOOLEAN DRIVING FUNCTION</u>
20	K25	$(P_{12(g)} < P_{14}) \cdot (251 \cdot \text{Reset}')'$
21	K26	$78 \cdot (P_{12} < P_6) \cdot (471 \cdot \text{Reset}')'$
22	K28	$\left[\text{FF } 11\text{B Set} + \text{FF } 11\text{C Set} \right]$ $+ \text{FF } 39\text{A Set} + \text{FF } 39\text{B Set}$
23	K62	$\text{FF } 11\text{B Set} + \text{FF } 11\text{C Set}$
24	K63	$\text{FF } 39\text{A Set} + \text{FF } 39\text{B Set}$
25	$K_{IC} P_{12GH_2}$	$\text{FF } 08\text{B Reset} \cdot \text{Hold}'$
26	$K_{IC} P_{14GH_2}$	$\text{FF } 08\text{B Reset} \cdot \text{Hold}'$
27	$K_{IC} \dot{W}_{15GH_2}$	$\text{FF } 08\text{B Reset} \cdot \text{Hold}'$
28	$K_{IC} P_{8GH_2}$	$\left[\text{Hold}' \cdot \text{FF } 08\text{B Reset} \right]$ $\cdot \left[\text{Reset} + (201 \cdot \text{Reset}') + \left\{ (251 \cdot \text{Reset}') \right. \right.$ $\left. \cdot (201 \cdot \text{Reset}')' \right\} \left. \right]$
29	$K_O P_{12GH_2}$	$\text{FF } 08\text{B Set} \cdot \text{Hold}'$
30	$K_O P_{14GH_2}$	$\text{FF } 08\text{B Set} \cdot \text{Hold}'$
31	$K_O \dot{W}_{15GH_2}$	$\text{FF } 08\text{B Set} \cdot \text{Hold}'$

LOGIC EQN NO.	FUNCTION*	BOOLEAN DRIVING FUNCTION
32	$K_0 P_{8GH_2}$	FF 08B Set • Hold'
33	$K_0 P_{6GHe}$	FF 08A Set • Hold'
34	$K_0 P_{13GH_2}$	FF 11B Set • Hold'
35	$K_{IC} P_{13GH_2}$	FF 11B Reset • Hold'
36	$K_0 P_{13GHe}$	FF 11C Set • Hold'
37	$K_{IC} P_{13GHe}$	FF 11C Reset • Hold'
38	$K_0 P_{12GHe}$	FF 11A Set • Hold'
39	$K_{IC} P_{12GHe}$	FF 11A Reset • Hold'
40	$K_{IC} P_{6GHe}$	FF 08A Reset • Hold'
41	$K_0 P_5$	FF 39D Set • Hold'
42	$K_0 \dot{W}_4$	FF 39D Set • Hold'
43	$K_0 \ddot{W}_4$	FF 39D Reset • Hold'
44	$K_{IC} P_5$	FF 39D Reset • Hold'
45	$\dot{W}_4$	FF 39D Reset • Hold'
46	$\ddot{W}_4$	FF 39D Reset • Hold'

<u>LOGIC</u> <u>EQN NO.</u>	<u>FUNCTION*</u>	<u>BOOLEAN DRIVING FUNCTION</u>
47	$K_0 \dot{W}_{16LH_2}$	FF 39A Set · Hold'
48	$K_0 P_{16LH_2}$	FF 39A Set · Hold'
49	$K_0 P_{13LH_2}$	FF 39A Set · Hold'
50	$K_{IC} \dot{W}_{16LH_2}$	FF 39A Reset · Hold'
51	$K_{IC} P_{16LH_2}$	FF 39A Reset · Hold'
52	$K_{IC} P_{13LH_2}$	FF 39A Reset · Hold'
53	$K_0 \dot{W}_1$	FF 39B Set · Hold'
54	$K_0 P_2$	FF 39B Set · Hold'
55	$K_0 P_3$	FF 39B Set · Hold'
56	$K_0 \dot{W}_{16LN_2}$	FF 39B Set · Hold'
57	$K_0 P_{16LN_2}$	FF 39B Set · Hold'
58	$K_0 P_{13LN_2}$	FF 39B Set · Hold'
59	$K_{IC} \dot{W}_1$	FF 39B Reset · Hold'
60	$K_{IC} P_2$	FF 39B Reset · Hold'
61	$K_{IC} P_3$	FF 39B Reset · Hold'

<u>LOGIC EQN NO.</u>	<u>FUNCTION*</u>	<u>BOOLEAN DRIVING FUNCTION</u>
62	$K_{IC} P_{13}$	FF 39B Reset $\cdot$ Hold'
63	$K_{IC} P_{16}$	FF 39B Reset $\cdot$ Hold'
64	$K_{IC} \dot{W}_{16}$	FF 39B Reset $\cdot$ Hold'
65	$K_O P_{15}$	FF 08C Set $\cdot$ Hold'
66	$K_{IC} P_{15}$	FF 08C Reset $\cdot$ Hold'
67	$K_O P_{10}$	FF 08D Set $\cdot$ Hold'
68	$K_O P_{11}$	FF 08D Set $\cdot$ Hold'
69	$K_O \dot{W}_{10}$	FF 08D Set $\cdot$ Hold'
70	$K_{IC} P_{10}$	FF 08D Reset $\cdot$ Hold'
71	$K_{IC} P_{11}$	FF 08D Reset $\cdot$ Hold'
72	$K_{IC} W_{10}$	FF 08D Reset $\cdot$ Hold'
73	FF 08A Set	$(471 \cdot \text{Reset}') \cdot [(201 \cdot \text{Reset}') \cdot (21 \cdot \text{Reset}')]'$
74	FF 08A Reset	$\text{Reset} + [(201 \cdot \text{Reset}') \cdot (251 \cdot \text{Reset}')]$
75	FF 08B Set	$(201 \cdot \text{Reset}') \cdot (251 \cdot \text{Reset}')$
76	FF 08B Reset	$[(201 \cdot \text{Reset}') \cdot (251 \cdot \text{Reset}')]'$ $\cdot [\text{FF 11A Set} + \text{Reset}]$

<u>LOGIC EQN NO.</u>	<u>FUNCTION*</u>	<u>BOOLEAN DRIVING FUNCTION</u>
77	FF 08C Set	472•FF 08D Set
78	FF 08C Reset	$\text{Reset} + \left\{ [P_2 > P_3] \cdot [517 \cdot 545 \cdot \text{Reset}'] \right.$ $\left. \cdot [(458 + 459) \cdot \left\{ 472 \cdot (107 \cdot \text{Reset}') \right\}]' \right\}$
79	FF 08D Set	$(107 \cdot \text{Reset}') \cdot \left[\text{Reset} + \left\{ [P_2 > P_3] \cdot [517 \cdot 545 \cdot \text{Reset}'] \right. \right.$ $\left. \cdot [(458 + 459) \cdot \left\{ 472 \cdot (107 \cdot \text{Reset}') \right\}]' \right\}$
80	FF 08D Reset	$\text{Reset} + \left\{ [P_2 > P_3] \cdot [517 \cdot 545 \cdot \text{Reset}'] \right.$ $\left. \cdot [(458 + 459) \cdot \left\{ 472 \cdot (107 \cdot \text{Reset}') \right\}]' \right\}$
81	FF 11A Set	$[(201 \cdot \text{Reset}') \cdot (251 \cdot \text{Reset}')]'$ $\cdot [\text{FF 08A Set} \cdot 78]$
82	FF 11A Reset	$(\text{FF 08B Set} \cdot \text{Reset}) \cdot \left\{ [(201 \cdot \text{Reset}') \cdot (251 \cdot \text{Reset}')]' \right.$ $\left. \cdot [\text{FF 08A Set} \cdot 78] \right\}$
83	FF 11B Set	FF 08B Set • (454 + 460) • (P ₁₂ > P ₁₃)
84	FF 11B Reset	$[\text{FF 08B Set} \cdot (454 + 460) \cdot (P_{12} > P_{13})]'$ $\cdot [\text{Reset} + \text{FF 11C Set} + \text{FF 39A Set} + \text{FF 39B Set}]$

<u>LOGIC</u> <u>EQN NO.</u>	<u>FUNCTION*</u>	<u>BOOLEAN DRIVING FUNCTION</u>
85	FF 11C Set	$ \begin{aligned} & [\text{FF 08B Set} \cdot (454 + 460) \cdot (P_{12} > P_{13})]' \\ & \cdot [(P_4 < P_1) \cdot (\text{Reset}' \cdot 517 \cdot 545)]' \\ & \cdot \left\{ (P_4 < P_9) \cdot \left[\left\{ \text{FF 08C Set} \cdot (458 + 459) \right\} \right. \right. \\ & \cdot \left. \left. \left\{ P_{13} > P_{12} \right\}' \cdot [472 \cdot (107 \cdot \text{Reset}')] \right\}' \right\} \\ & \cdot \left\{ [(454 + 460) \cdot \text{FF 11A Set}] \right. \\ & \cdot \left. \left[\left\{ 78 \cdot (471 \cdot \text{Reset}') \right\}' \cdot (P_{13} > P_{12}) \right]' \right\} \end{aligned} $
86	FF 11C Reset	$ \begin{aligned} & \left[\text{FF 08B Set} \cdot (454 + 460) \cdot (P_{12} > P_{13}) \right]' \\ & \cdot [(P_4 < P_1) \cdot (\text{Reset}' \cdot 517 \cdot 545)]' \\ & \cdot \left\{ (P_4 < P_9) \cdot \left[\left\{ \text{FF 08C Set} \cdot (458 + 459) \right\} \right. \right. \\ & \cdot \left. \left. \left\{ (P_{13} > P_{12})' \cdot [472 \cdot (107 \cdot \text{Reset}')] \right\}' \right\} \right\} \\ & \cdot \left\{ [(454 + 460) \cdot \text{FF 11A Set}] \cdot \left[\left\{ 78 \cdot (471 \cdot \text{Reset}') \right\} \right. \right. \\ & \cdot \left. \left. (P_{13} > P_{12}) \right]' \right\} \\ & \cdot [\text{FF 11B Set} + \text{Reset} + \text{FF 39A Set} + \text{FF 39B Set}] \end{aligned} $

<u>LOGIC</u> <u>EQN NO.</u>	<u>FUNCTION*</u>	<u>BOOLEAN DRIVING FUNCTION</u>
87	FF 39A Set	$ \begin{aligned} & [\text{FF 08B Set} \cdot (454 + 460) \cdot (P_{12} > P_{13})]' \\ & \cdot \left[\left\{ [(454 + 460) \cdot \text{FF 11A Set}] \right. \right. \\ & \cdot [\left\{ 78 \cdot (471 \cdot \text{Reset}') \right\}' \cdot (P_{13} > P_{12})]' \left. \right\} \\ & \cdot (P_4 > P_9)' \left. \right] \\ & \cdot \left\{ [\text{FF 08C Set} \cdot (458 + 459)] \right. \\ & \cdot [(P_{13} > P_{12})' \cdot (472 \cdot [107 \cdot \text{Reset}'])] \left. \right\} \end{aligned} $
88	FF 39A Reset	$ \begin{aligned} & [\text{FF 08B Set} \cdot (454 + 460) \cdot (P_{12} > P_{13})]' \\ & \cdot \left\{ [(454 + 460) \cdot \text{FF 11A Set}] \right. \\ & \cdot [\left\{ 78 \cdot (471 \cdot \text{Reset}') \right\}' \cdot (P_{13} > P_{12})' \cdot (P_4 < P_9)'] \\ & \cdot \left\{ [\text{FF 08C Set} \cdot (458 + 459)] \right. \\ & \cdot \left[(P_{13} > P_{12})' \cdot (472 \cdot [107 \cdot \text{Reset}'])] \right\} \left. \right] \\ & \cdot [\text{FF 11B Set} + \text{FF 11C Set} + \text{Reset} + \text{FF 39B Set}] \end{aligned} $

<u>LOGIC EQN NO.</u>	<u>FUNCTION*</u>	<u>BOOLEAN DRIVING FUNCTION</u>
89	FF 39B Set	$\left[\left\langle \text{FF 08B Set} \cdot (454 + 460) \cdot (P_{12} > P_{13}) \right\rangle' \right.$ $\cdot \left\langle \left[(454 + 460) \cdot \text{FF 11A Set} \right] \right.$ $\cdot \left[\left\langle 78 \cdot (471 \cdot \text{Reset}') \right\rangle' \cdot (P_3 > P_{12}) \right]' \left. \right]$ $\cdot \left[\left[P_4 < P_1 \right]' \right]' \cdot \left\langle \text{FF 08 Set} \cdot (458 + 459) \right\rangle'$ $\cdot \left\langle 517 \cdot 545 \cdot \text{Reset}' \right\rangle' \cdot [P_2 > P_3]$
90	FF 39B Reset	$\left[\left\langle \text{FF 08B Set} \cdot (454 + 460) \cdot (P_{12} > P_{13}) \right\rangle' \right.$ $\cdot \left\langle \left[(454 + 460) \cdot \text{FF 11A Set} \right] \right.$ $\cdot \left[\left\langle 78 \cdot (471 \cdot \text{Reset}') \right\rangle' \cdot (P_3 > P_{12}) \right]' \left. \right]$ $\cdot \left[\left[P_4 < P_1 \right]' \right]' \cdot \left\langle \text{FF 08 Set} \cdot (458 + 459) \right\rangle'$ $\cdot \left\langle 517 \cdot 545 \cdot \text{Reset}' \right\rangle' \cdot [P_2 > P_3]$ $\cdot \left(\text{FF 11B Set} + \text{FF 11C Set} + \text{FF 39A Set} + \text{Reset} \right)$

<u>LOGIC EQN NO.</u>	<u>FUNCTION*</u>	<u>BOOLEAN DRIVING FUNCTION</u>
91	FF 39D Set	471 • Reset'
92	FF 39D Reset	Reset
93	K178	472 • 10 mv
94	K79	472 • 10 mv
95	K87	107 • 10 mv
96	K101	(459 + 458) • 10 mv
97	K59A	(459 + 458) • 10 mv
98	K70A	$\frac{\theta}{-CSV}$ • 10 mv
99	K70B	$\frac{\theta}{-CSV}$ • 10 mv
100	KZA	$\frac{\theta}{-CSV}$ • 10 mv
101	K66B	$\frac{\theta}{-CSV}$ • 10 mv
102	KZB	$\frac{\theta}{-CSV}$ • 10 mv
103	K67B	$\frac{\theta}{-CSV}$ • 10 mv
104	K100	517 • 10 mv
105	K80	545 • 10 mv

<u>LOGIC EQN NO.</u>	<u>FUNCTION*</u>	<u>BOOLEAN DRIVING FUNCTION</u>
106	K59B	545.10 mv
107	K65B	(454 + 460) · 10 mv
108	KYA	(454 + 460) · 10 mv
109	K109	(454 + 460) · 10 mv
110	K64A	(454 + 460) · 10 mv
111	K111A	78.10 mv
112	KXA	78.10 mv
113	KXB	78.10 mv
114	K111B	78.10 mv
115	K110A	471.10 mv
116	K110B	471.10 mv
117	K110C	471.10 mv
118	K105A	251.10 mv
119	K105B	251.10 mv
120	K105C	251.10 mv

<u>LOGIC EQN NO.</u>	<u>FUNCTION*</u>	<u>BOOLEAN DRIVING FUNCTION</u>
121	K106	$201 \cdot 10 \text{ mv}$
122	K107	$201 \cdot 10 \text{ mv}$
123	KYB	$(454 + 460) \cdot 10 \text{ mv}$
124	K65A	$(454 + 460) \cdot 10 \text{ mv}$
125	K64B	$(454 + 460) \cdot 10 \text{ mv}$

3.2.2.9.2.2 COOLDOWN-HOLD EQUATIONS

<u>LOGIC EQN NO.</u>	<u>VARIABLE</u>	<u>AMPLIFIER</u>	<u>BOOLEAN DRIVING FUNCTION</u>
126	$P_{-15LH_2}/2$	A5956	$(472 \cdot 10 \text{ mv}) \cdot [(458 + 459) \cdot 10 \text{ mv}]$
127	$P_{-3LN_2}/2$	A5974	$(545 \cdot 10 \text{ mv}) \cdot (517 \cdot 10 \text{ mv})$
128	P_{-8GH_2}	A5913	$(251 \cdot 10 \text{ mv}) \cdot (201 \cdot 10 \text{ mv})$
129	P_{-13GHe}	A5843	$(CSV \cdot 10 \text{ mv}) \cdot [(454 + 460) \cdot 10 \text{ mv}]$
130	P_{-13GH_2}	A5844	$(CSV \cdot 10 \text{ mv}) \cdot [(454 + 460) \cdot 10 \text{ mv}]$
131	P_{-12GHe}	A5888	$[(454 + 460) \cdot 10 \text{ mv}] \cdot (78 \cdot 10 \text{ mv})$
132	P_{-6GHe}	A6006	$(78 \cdot 10 \text{ mv}) \cdot (471 \cdot 10 \text{ mv})$

3.2.3 Cooldown Set-up Procedures

3.2.3.1 Actuator Simulation Set-up Procedure - Typical RSV-CSV

3.2.3.1.1 General

A circuit is used to simulate the actuators of the two-state valves: e.g., the various Remote Shut-off Valves (RSV), the Cooldown Shut-off Valve (CSV), and the Pump Shut-off Valve (PSV) in the Engine Block of the TSS.

3.2.3.1.2 Procedure

The circuit employs a single operational amplifier to accomplish a second-order lag system and is quite flexible in the following ways:

(a) Can be adjusted for various transfer functions by varying the resistors per section 2.4.1.3 R_0 , R_1 , R' , R'' .

(b) Can be connected to simulate valves having lesser opening than closing time, equal opening and closing times, lesser closing than opening time, using Relay Contact Sets A & B.

(c) Transforms or converts the Control Point 28 VDC ground system to the TSS ground (SRC) using Relay C-form set A.

(d) Refer to section 2.4.1.5 for detailed procedure of setting up an actuator.

(e) Set all associated potentiometer gains to the value shown on AGC Drawing 1114289.

The Computing Sciences Library, AGC Sacramento, has a digital program

[CIRCUIT OPTIMIZATION - VALVE ACTUATOR SIMULATION-W-76793] that selects the R & C values for the circuit; program inputs are the steady state gain K, and the two time constants, τ_1 , τ_2 , from the transfer function in following form:

$$\frac{\text{LIFT}}{\text{LIFT}_{\text{Demand}}} (S) = \frac{K}{(1 + \tau_1 s)(1 + \tau_2 s)}$$

3.2.3.2 Actuator - Simulation Set-up Procedures - Typical PCV -

3.2.3.2.1 General

A general analog circuit is designed to simulate the analog control valves (PCV). The circuit is typical of the simulation used in each fluid subsystem. Amplifiers B, C, and D are used to form the second order lag network of the transfer function whose specific linear characteristics are controlled by gains a_1G_2 , b_1G_1 , d_1b_3 , C_1G_4 . The non-linear characteristics are simulated by the velocity and position limiters as well as amplifier A which provides a synthesis of the NO-motion response domain of the lower 20% of the demand voltage or current command. The 3.0K ohm shunt resistor synthesizes the effective electrical load impedance the typical Process System Controller experiences when connected to the actual valve actuator.

3.2.3.2.2 Procedure

The setup procedure for the PCV actuators are the following: (1) Verify that all power supply voltage in that specific rack are at their proper values. (2) Verify that all amplifiers are properly balanced. (3) Linear gains (the gains of the small signal transfer function) via potentiometers A, B, C, D as specified in section 2.4.1.3, see AGC Drawing 1114289 for specific potentiometer gain settings. (4) the velocity and

position limiters around amplifiers B and C as specified in Section 2.4.1.1 (see AGC Drawing 1114289 for specific potentiometer settings).

3.2.3.2.3 Operational Check

An input output DC gain check must agree with the transfer function. In these cases it is equal to 0.333. A transfer function check is necessary to verify the circuit dynamics.

3.2.3.3 Cooldown Potentiometer Gain Settings

3.2.3.3.1 General

The total gain of a given scaled variable required to satisfy the physical equations is given by the scaled equations in the following sections. The total gain is the product of two gains: (a) ratio of feedback to input for the given scaled variable of the particular amplifier, and (b) the gain of the input potentiometer for the given scaled variable. (Reference Section 2.4.1.3, "Potentiometer Gain Settings")

3.2.3.3.2 Scaled equations - cooldown

$$(1) \quad \text{Equations:} \quad (a) \quad P_4 = 2500 \left[1 - 1.128 \times 10^{-4} \int_0^t \dot{w}_4 dt \right]^{1.67}$$

$$(b) \quad T_2 = 560 \left[1 - 1.128 \times 10^{-4} \int_0^t \dot{w}_4 dt \right]^{0.67}$$

Maxima:

$$P_4 = 2500 \text{ psia}$$

$$\dot{w}_4 = 50 \text{ lb/sec}$$

$$T_2 = 560^\circ\text{R}$$

Scaled Equations:

$$2500 \underline{P}_4 = 2500 \left[1 - 1.128 \times 10^{-4} \int_0^t 50 \dot{w}_4 dt \right]^{1.67}$$

$$(a) \quad \underline{P}_4 = \left[1 - 0.564 \times 10^{-2} \int_0^t \dot{w}_4 dt \right]^{1.67}$$

$$560 \underline{T}_2 = 560 \left[1 - 1.128 \times 10^{-4} \int_0^t 50 \dot{w}_4 dt \right]^{0.67}$$

$$(b) \quad \underline{T}_2 = \left[1 - 0.564 \times 10^{-2} \int_0^t \dot{w}_4 dt \right]^{0.67}$$

(2) Equations: (a) $\ddot{w}_4 = 1.36 (P_4 - 0.099 \dot{w}_4^2 - P_5)$

(b) $\dot{w}_4 = \int_0^t w_4 dt$

Maxima:

$$\dot{w}_4 = 50 \text{ lb/sec}$$

$$\ddot{w}_4 = 500 \text{ lb/sec}^2$$

$$P_4 = 2500 \text{ psia}$$

$$P_5 = 2500 \text{ psia}$$

Scaled Equations:

$$500 \ddot{w}_4 = 1.36 (2500 \underline{P}_4 - 0.099 (50)^2 \dot{w}_4^2 - 2500 \underline{P}_5)$$

$$(a) \quad \ddot{w}_4 = 6.80 (\underline{P}_4 - 0.099 \dot{w}_4^2 - \underline{P}_5)$$

$$50 \dot{w}_4 = \int_0^t 500 \ddot{w}_4 dt$$

$$(b) \quad \dot{w}_4 = 10 \int_0^t \ddot{w}_4 dt$$

(3) Equations: (a) $\dot{P}_5 = 0.0191 T_2 (\dot{w}_4 - \dot{w}_5)$

(b) $\dot{P}_5 = \int_0^t \dot{P}_5 dt + P_5 \text{ (I.C.)}$

Maxima:

$$\dot{P}_5 = 2500 \frac{\text{psia}}{\text{sec}}$$

$$P_5 = 2500 \text{ psia}$$

$$T_2 = 560^\circ\text{R}$$

$$\dot{w}_4 = \dot{w}_5 = 50 \text{ lb/sec}$$

Scaled Equations:

$$2500 \dot{\underline{P}}_5 = (0.0191)(560) \underline{T}_2 (50 \dot{\underline{w}}_4 - 50 \dot{\underline{w}}_5)$$

(a) $\dot{\underline{P}}_5 = 0.2139 \underline{T}_2 (\dot{\underline{w}}_4 - \dot{\underline{w}}_5)$

$$2500 \underline{P}_5 = \int_0^t 2500 \dot{\underline{P}}_5 dt + P_5 \text{ (I.C.)}$$

(b) $\underline{P}_5 = \int_0^t \dot{\underline{P}}_5 dt + \frac{P_5 \text{ (I.C.)}}{2500}$

(4) Equation: $\dot{w}_5 = 0.323 A_{e\ 471} N_{s\ 471} P_5 / \sqrt{T_2}$

Maxima:

$$\dot{w}_5 = 50 \text{ lb/sec}$$

$$A_{e\ 471} = 30 \text{ in.}^2$$

$$N_{s\ 471} = 1$$

$$P_5 = 2500 \text{ psia}$$

$$T_2 = 560^\circ\text{R}$$

Scaled Equation:

$$50 \dot{w}_5 = (0.323) (30) (1) (2500) \frac{A_{e\ 471}}{A_{e\ 471}} \frac{N_{s\ 471}}{N_{s\ 471}} \frac{P_5}{P_5} / \sqrt{560} \sqrt{T_2}$$

$\dot{w}_5 = 20.48 \frac{A_{e\ 471}}{A_{e\ 471}} \frac{N_{s\ 471}}{N_{s\ 471}} \frac{P_5}{P_5} / \sqrt{T_2}$
--

(5) Equations:

(a) $\dot{P}_6 = 0.538 T_2 (\dot{w}_5 - \dot{w}_6)$

(b) $P_6 = \int_0^t \dot{P}_6 dt + P_6 \text{ (I.C.)}$

Maxima:

$$\dot{P}_6 = 2500 \text{ psia/sec}$$

$$P_6 = 2500 \text{ psia}$$

$$\dot{w}_5 = \dot{w}_6 = 50 \text{ lb/sec}$$

$$T_2 = 560^\circ\text{R}$$

Scaled Equations:

$$2500 \dot{\underline{P}}_6 = (0.538)(560) \underline{T}_2 (50 \dot{\underline{w}}_5 - 50 \dot{\underline{w}}_6)$$

$$(a) \quad \boxed{\dot{\underline{P}}_6 = 6.026 \underline{T}_2 (\dot{\underline{w}}_5 - \dot{\underline{w}}_6)}$$

$$2500 \underline{P}_6 = \int_0^t 2500 \dot{\underline{P}}_6 dt + P_6 \text{ (I.C.)}$$

$$(b) \quad \boxed{\underline{P}_6 = \int_0^t \dot{\underline{P}}_6 dt + \frac{P_6 \text{ (I.C.)}}{2500}}$$

(6) Equations: (a) $\dot{W}_6 = 0.323 A_{e78} N_{s78} P_6 / \sqrt{T_2}$

(b) $\dot{W} \geq 0$ (50CHV 685)

Maxima:

$$\dot{W}_6 = 50 \text{ lb/sec}$$

$$A_{e78} = 29 \text{ in.}^2$$

$$N_{s78} = 1$$

$$P_6 = 2500 \text{ psia}$$

$$T_2 = 560^\circ\text{R}$$

Scaled Equation:

$$50 \dot{W}_6 = (0.323) (29) (1) (2500) \frac{A_{e78} N_{s78} P_6}{\sqrt{560} \sqrt{T_2}}$$

$\dot{W}_6 = 19.78 \frac{A_{e78} N_{s78} P_6}{\sqrt{T_2}}$
--

(7) Equations: (a) $\dot{P}_{12\text{GHe}} = 0.4305 T_2 (\dot{w}_6 - \dot{w}_{12\text{GHe}})$

(b) $P_{12\text{GHe}} = \int_0^t \dot{P}_{12\text{GHe}} dt + P_{12\text{GHe}} (\text{I.C.})$

Maxima:

$$\dot{P}_{12\text{GHe}} = 2500 \text{ psia/sec}$$

$$P_{12\text{GHe}} = 2500 \text{ psia}$$

$$T_2 = 560^\circ\text{R}$$

$$\dot{w}_6 = \dot{w}_{12\text{GHe}} = 50 \text{ lb/sec}$$

Scaled Equations:

$$2500 \dot{\underline{P}}_{12\text{GHe}} = (0.4305) (560) \underline{T}_2 (50 \dot{\underline{w}}_6 - 50 \dot{\underline{w}}_{12\text{GHe}})$$

(a) $\boxed{\dot{\underline{P}}_{12\text{GHe}} = 4.8216 \underline{T}_2 (\dot{\underline{w}}_6 - \dot{\underline{w}}_{12\text{GHe}})}$

$$2500 \underline{P}_{12\text{GHe}} = \int_0^t 2500 \dot{\underline{P}}_{12\text{GHe}} dt + P_{12} (\text{I.C.})$$

(b) $\boxed{\underline{P}_{12\text{GHe}} = \int_0^t \dot{\underline{P}}_{12\text{GHe}} dt + \frac{P_{12} (\text{I.C.})}{2500}}$

(8) Equations: (a) $\dot{w}_{12\text{GHe}} = 0.323 (A_{e454} + A_{e460}) \frac{N_{s454||460}}{\sqrt{T_2}}$

$$(P_{12\text{GHe}} - 0.011 \dot{w}_{12\text{GHe}}^2)$$

(b) $\dot{w}_{12\text{GHe}} \geq 0$ (50 CHV1721)

Maxima:

$$\dot{w}_{12\text{GHe}} = 50 \text{ lb/sec}$$

$$A_{e454} = A_{e460} = 34.00 \text{ in.}^2$$

$$N_{s454||460} = 1$$

$$P_{12\text{GHe}} = 2500 \text{ psia}$$

$$T_2 = 560^\circ\text{R}$$

Scaled Equation:

$$50 \dot{w}_{12\text{GHe}} = (0.323) (34 A_{e454} + A_{e460}) (1) \frac{N_{s454||460}}{\sqrt{560} \sqrt{T_2}} [2500 P_{12\text{GHe}} - 0.011 (50)^2 \dot{w}_{12\text{GHe}}^2]$$

$\dot{w}_{12\text{GHe}} = 23.21 (A_{e454} + A_{e460}) \frac{N_{s454 460}}{\sqrt{T_2}} (P_{12\text{GHe}} - 0.011 \dot{w}_{12\text{GHe}}^2)$

(9) Equations: (a) $\dot{P}_{13\text{GHe}} = 0.1128 T_2 (\dot{w}_{12\text{GHe}} - \dot{w}_{13\text{GHe}})$

(b) $P_{13\text{GHe}} = \int_0^t \dot{P}_{13\text{GHe}} dt + P_{13\text{GHe}} \text{ (I.C.)}$

Maxima:

$$\dot{P}_{13\text{GHe}} = 2500 \text{ psia/sec}$$

$$P_{13\text{GHe}} = 2500 \text{ psia}$$

$$T_2 = 560^\circ\text{R}$$

$$\dot{w}_{12\text{GHe}} = \dot{w}_{13\text{GHe}} = 50 \text{ lb/sec}$$

Scaled Equations:

$$2500 \dot{P}_{13\text{GHe}} = (0.1128) (560) T_2 (50 \dot{w}_{12\text{GHe}} - 50 \dot{w}_{13\text{GHe}})$$

$$(a) \quad \boxed{\dot{P}_{13\text{GHe}} = 1.263 T_2 (\dot{w}_{12\text{GHe}} - \dot{w}_{13\text{GHe}})}$$

$$2500 P_{13\text{GHe}} = \int_0^t 2500 \dot{P}_{13\text{GHe}} dt + P_{13} \text{ (I.C.)}$$

$$(b) \quad \boxed{P_{13\text{GHe}} = \int_0^t \dot{P}_{13\text{GHe}} dt + \frac{P_{13} \text{ (I.C.)}}{2500}}$$

(10) Equations: (a) $\dot{w}_{13\text{He}} = 0.323 A_{\text{eCDSV}} \frac{N_{\text{sCDSV}}}{\sqrt{T_2}} (P_{13\text{He}} - 0.0919 \dot{w}_{13\text{He}}^2)$

(b) $\dot{w}_{13\text{He}} \geq 0$ (CDCHV)

Maxima:

$$\dot{w}_{13\text{He}} = 50 \text{ lb/sec}$$

$$A_{\text{eCDSV}} = 30 \text{ in.}^2$$

$$N_{\text{sCDSV}} = 1$$

$$T_2 = 560^\circ\text{R}$$

$$P_{13\text{He}} = 2500 \text{ psia}$$

Scaled Equation:

$$50 \dot{w}_{13\text{He}} = (0.323) (30) (1) \frac{A_{\text{eCDSV}} N_{\text{sCDSV}}}{\sqrt{560} \sqrt{T_2}} \left[2500 P_{13\text{He}} - (0.0919) (50^2) \dot{w}_{13\text{He}}^2 \right]$$

$$\dot{w}_{13\text{He}} = 20.48 \frac{A_{\text{eCDSV}} N_{\text{sCDSV}}}{\sqrt{T_2}} (P_{13\text{He}} - 0.0919 \dot{w}_{13\text{He}}^2)$$

$$(11) \text{ Equation: } N_{\text{sCDSV}} = f \left(\frac{P_{13\text{GHe}} - 0.0919 \dot{w}_{13\text{GHe}}^2 - P_{e3}}{P_{13\text{GHe}} - 0.0919 \dot{w}_{13\text{GHe}}^2} \right)$$

Maxima:

$$N_{\text{sCDSV}} = 1$$

$$P_{13\text{GHe}} = 2500 \text{ psia}$$

$$\dot{w}_{13\text{GHe}} = 50 \text{ lb/sec}$$

$$P_{e3} = 1000 \text{ psia}$$

Scaled Equation:

$$(1) \frac{N_{\text{sCDSV}}}{1} = f \left(\frac{2500 \frac{P_{13\text{GHe}}}{2500} - 0.0919 (50)^2 \frac{\dot{w}_{13\text{GHe}}^2}{50^2} - 1000 \frac{P_{e3}}{1000}}{2500 \frac{P_{13\text{GHe}}}{2500} - 0.0919 (50)^2 \frac{\dot{w}_{13\text{GHe}}^2}{50^2}} \right)$$

$$\boxed{\frac{N_{\text{sCDSV}}}{1} = f \left(\frac{\frac{P_{13\text{GHe}}}{2500} - 0.0919 \frac{\dot{w}_{13\text{GHe}}^2}{50^2} - 0.4 \frac{P_{e3}}{1000}}{\frac{P_{13\text{GHe}}}{2500} - 0.0919 \frac{\dot{w}_{13\text{GHe}}^2}{50^2}} \right)}$$

$$(12) \text{ Equation: } N_{s78} = f \left(\frac{P_6 - P_{12GHe}}{P_6} \right)$$

Maxima:

$$P_6 = P_{12GHe} - 2500 \text{ psia}$$

$$N_{s78} = 1$$

Scaled Equation:

$$(1) \frac{N_{s78}}{1} = f \frac{2500 \frac{P_6}{1} - 2500 \frac{P_{12GHe}}{1}}{2500 \frac{P_6}{1}}$$

$$\frac{N_{s78}}{1} = f \left(\frac{\frac{P_6}{1} - \frac{P_{12GHe}}{1}}{\frac{P_6}{1}} \right)$$

$$(13) \text{ Equation: } N_{s471} = f \left(\frac{P_5 - P_6}{P_5} \right)$$

Maxima:

$$N_{s471} = 1$$

$$P_5 = P_6 = 2500 \text{ psia}$$

Scaled Equation:

$$(1) \frac{N_{s471}}{1} = f \left(\frac{2500 \frac{P_5}{1} - 2500 \frac{P_6}{1}}{2500 \frac{P_5}{1}} \right)$$

$$N_{s471} = f \left(\frac{\frac{P_5}{1} - \frac{P_6}{1}}{\frac{P_5}{1}} \right)$$

$$(14) \text{ Equation: } N_{s454||460} = f \left(\frac{P_{12GHe} - 0.011 \dot{w}_{12GHe}^2 - P_{13GHe}}{P_{12GHe} - 0.011 \dot{w}_{12GHe}^2} \right)$$

Maxima:

$$N_{s454||460} = 1$$

$$P_{12GHe} - P_{13GHe} = 2500 \text{ psia}$$

$$\dot{w}_{12GHe} = 50 \text{ lb/sec}$$

Scaled Equation:

$$(1) \frac{N_{s454||460}}{1} = f \left(\frac{2500 \frac{P_{12GHe}}{2500} - 0.011 (50)^2 \frac{\dot{w}_{12GHe}^2}{50^2} - \frac{P_{13GHe}}{2500}}{2500 \frac{P_{12GHe}}{2500} - 0.011 (50)^2 \frac{\dot{w}_{12GHe}^2}{50^2}} \right)$$

$$\boxed{\frac{N_{s454||460}}{1} = f \left(\frac{\frac{P_{12GHe}}{2500} - 0.011 \frac{\dot{w}_{12GHe}^2}{50^2} - \frac{P_{13GHe}}{2500}}{\frac{P_{12GHe}}{2500} - 0.011 \frac{\dot{w}_{12GHe}^2}{50^2}} \right)}$$

3.2.3.3.2.1 GH₂ Scaled Equations

(1) Equations:

$$(a) \quad P_7 = P_7 (0) = 2500 \text{ psia}$$

$$(b) \quad T_3 = T_3 (0) = 560^\circ\text{R}$$

Maxima:

$$P_7 = 2500 \text{ psia}$$

$$T_3 = 560^\circ\text{R}$$

Scaled Equations:

$$2500 \frac{P_7}{P_7} = 2500$$

$$(a) \quad \frac{P_7}{P_7} = 1$$

$$560 \frac{T_3}{T_3} = 560$$

$$(b) \quad \frac{T_3}{T_3} = 1.00$$

(2) Equations:

$$(a) \quad \dot{w}_7 = 0.1402 N_{s201} A_{e201} \frac{P_7}{\sqrt{T_3}}$$

$$(b) \quad \dot{w}_7 \geq 0 \quad (50\text{CHV } 117)$$

Maxima:

$$\dot{w}_7 = 50 \text{ lb/sec}$$

$$N_{s201} = 1$$

$$A_{e201} = 29.00 \text{ in.}^2$$

$$P_7 = 2500 \text{ psia}$$

$$T_3 = 560^\circ\text{R} \quad \text{Scale to } 560^\circ\text{R}$$

Scaled Equation:

$$50 \dot{\underline{w}}_7 = (0.1402) (1) (29) \frac{N_{s201}}{A_{e201}} (2500) \frac{P_7}{\sqrt{560} \sqrt{T_3}}$$

$$(a) \dot{\underline{w}}_7 = 8.67 \frac{N_{s201}}{A_{e201}} \frac{P_7}{\sqrt{T_3}}$$

(3) Equations:

$$(a) \dot{P}_8 = 0.0463 T_3 (\dot{\underline{w}}_7 - \dot{\underline{w}}_8)$$

$$(b) \dot{P}_8 = \int_0^t P_8 dt + P_8 \text{ (I.C.)}$$

Maxima:

$$\dot{P}_8 = 2500 \text{ psia/sec}$$

$$P_8 = 2500 \text{ psi}$$

$$T_8 = 560^\circ R$$

$$\dot{\underline{w}}_7 = 50 \text{ lb/sec}$$

Scaled Equations:

$$2500 \dot{P}_8 = (0.0463) (560) T_3 (50 \dot{\underline{w}}_7 - 50 \dot{\underline{w}}_8)$$

$$(a) \dot{\underline{P}}_8 = 0.518 T_3 (\dot{\underline{w}}_7 - \dot{\underline{w}}_8)$$

$$2500 \underline{P}_8 = \int_0^t 2500 \dot{\underline{P}}_8 dt + P_8 \text{ (I.C.)}$$

$$(b) \underline{P}_8 = \int_0^t \dot{\underline{P}}_8 dt + \frac{P_8 \text{ (I.C.)}}{2500}$$

(4) Equation: $\dot{w}_8 = 0.1402 \frac{A_{e251}}{N_{s251}} (P_8 - 0.1812 \dot{w}_8^2) / \sqrt{T_3}$

Maxima:

$$\dot{w}_8 = 50 \text{ lb/sec}$$

$$A_{e251} = 9.50 \text{ in.}^2$$

$$N_{s251} = 1$$

$$P_8 = 2500 \text{ psia}$$

$$T_3 = 560^\circ\text{R}$$

Scaled Equation:

$$50 \frac{\dot{w}_8}{50} = \frac{(0.1402)(9.5)(1)}{\sqrt{560} \sqrt{T_3}} \frac{A_{e251}}{N_{s251}} (2500 \frac{P_8}{2500} - 0.1812 \frac{\dot{w}_8^2}{(50)^2} (50)^2)$$

$$\frac{\dot{w}_8}{50} = 2.815 \frac{A_{e251}}{N_{s251}} (\frac{P_8}{2500} - 0.1812 \frac{\dot{w}_8^2}{(50)^2}) / \sqrt{T_3}$$

(5) Equations:

$$(a) \dot{P}_{14} = 1.065 T_3 (\dot{w}_8 - \dot{w}_{15})$$

$$(b) P_{14} = \int_0^t \dot{P}_{14} dt + P_{14} \text{ (I.C.)}$$

Maxima:

$$\dot{P}_{14} = 2500 \text{ psia/sec}$$

$$P_{14} = 2500 \text{ psia}$$

$$T_3 = 560^\circ\text{R}$$

$$\dot{w}_8 = \dot{w}_{15} = 50 \text{ lb/sec}$$

Scaled Equations:

$$2500 \dot{\underline{P}}_{14} = (1.065) (560) \underline{T}_3 (50 \dot{\underline{w}}_8 - 50 \dot{\underline{w}}_{15})$$

$$(a) \quad \underline{P}_{14} = 11.93 \underline{T}_3 (\dot{\underline{w}}_8 - \dot{\underline{w}}_{15})$$

$$2500 \underline{P}_{14} = \int_0^t 2500 \dot{\underline{P}}_{14} dt + \underline{P}_{14} \text{ (I.C.)}$$

$$(b) \quad \underline{P}_{14} = \int_0^t \dot{\underline{P}}_{14} dt + \frac{\underline{P}_{14} \text{ (I.C.)}}{2500}$$

(6) Equations:

$$(a) \quad \dot{\underline{w}}_{15} = 4.02 (\underline{P}_{14} - 0.1014 \dot{\underline{w}}_{15}^2 - \underline{P}_{12} \text{ GH}_2)$$

$$(b) \quad \dot{\underline{w}}_{15} = \int_0^t \dot{\underline{w}}_{15} dt$$

$$(c) \quad \dot{\underline{w}}_{15} \geq 0 \quad (50 \text{ CHV } 496)$$

Maxima:

$$\dot{\underline{w}}_{15} = 2500 \text{ lb/sec}^2$$

$$\dot{\underline{w}}_{15} = 50 \text{ lb/sec}$$

$$\underline{P}_{14} = 2500 \text{ psia}$$

$$\underline{P}_{12} \text{ GH}_2 = 2500 \text{ psia}$$

Scaled Equations:

$$2500 \dot{\underline{w}}_{15} = (4.02) (2500 \underline{P}_{14} - 0.1014 (50)^2 \dot{\underline{w}}_{15}^2 - 2500 \underline{P}_{12} \text{ GH}_2)$$

$$(a) \dot{\underline{w}}_{15} = 4.02 (\underline{P}_{14} - 0.1014 \dot{\underline{w}}_{15}^2 - \underline{P}_{12} \text{ GH}_2)$$

$$50 \dot{\underline{w}}_{15} = \int_0^t 2500 \dot{\underline{w}}_{15} dt$$

$$(b) \underline{w} = 50 \int_0^t \dot{\underline{w}}_{15} dt$$

(7) Equations:

$$(a) \dot{\underline{P}}_{12} \text{ GH}_2 = 0.853 T_3 (\dot{\underline{w}}_{15} - \dot{\underline{w}}_{12} \text{ GH}_2)$$

$$(b) \underline{P}_{12} \text{ GH}_2 = \int_0^t \dot{\underline{P}}_{12} \text{ GH}_2 dt + \underline{P}_{12} (\text{I.C.})$$

Maxima:

$$\dot{\underline{P}}_{12} \text{ GH}_2 = 2500 \text{ psia/sec}$$

$$\underline{P}_{12} \text{ GH}_2 = 2500 \text{ psia}$$

$$T_3 = 560^\circ\text{R}$$

$$\dot{\underline{w}}_{15} = \dot{\underline{w}}_{12} \text{ GH}_2 = 50 \text{ lb/sec}$$

Scaled Equations:

$$2500 \dot{\underline{P}}_{12} \text{ GH}_2 = (0.853) (560) \underline{T}_3 (50 \dot{\underline{W}}_{15} - 50 \dot{\underline{W}}_{12} \text{ GH}_2)$$

$$(a) \dot{\underline{P}}_{12} \text{ GH}_2 = 9.55 \underline{T}_3 (\dot{\underline{W}}_{15} - \dot{\underline{W}}_{12} \text{ GH}_2)$$

$$2500 \underline{P}_{12} \text{ GH}_2 = \int_0^t 2500 \dot{\underline{P}}_{12} \text{ GH}_2 dt + \underline{P}_{12} \text{ (I.C.)}$$

$$(b) \underline{P}_{12} \text{ GH}_2 = \int_0^t \dot{\underline{P}}_{12} \text{ GH}_2 dt + \frac{\underline{P}_{12} \text{ (I.C.)}}{2500}$$

(8) Equations:

$$(a) \dot{\underline{W}}_{12} \text{ GH}_2 = 0.1402 (\underline{A}_{e460} + \underline{A}_{e454}) \frac{N_{s454//460}}{\sqrt{\underline{T}_3}}$$

$$(\underline{P}_{12} \text{ GH}_2 - 0.0977 \dot{\underline{W}}_{12} \text{ GH}_2)$$

$$(b) \dot{\underline{W}}_{12} \text{ GH}_2 \geq 0 \quad (50 \text{ CHV } 1721)$$

Maxima:

$$\dot{\underline{W}}_{12} \text{ GH}_2 = 50 \text{ lb/sec}$$

$$\underline{A}_{e460} = \underline{A}_{e454} = 34.00 \text{ in.}^2$$

$$N_{s454//460} = 1$$

$$\underline{P}_{12} \text{ GH}_2 = 2500 \text{ psia}$$

$$\underline{T}_3 = 560^\circ\text{R}$$

Scaled Equation:

$$50 \dot{W}_{12 \text{ GH}_2} = (0.1402) (34 \underline{A}_{e460} + 34 \underline{A}_{e454}) \frac{(1) \underline{N}_{s460//454}}{\sqrt{560} \sqrt{T_3}} \left[2500 \underline{P}_{12 \text{ GH}_2} - 0.0977 (50^2) \dot{W}_{12 \text{ GH}_2}^2 \right]$$

$$\dot{W}_{12 \text{ GH}_2} = 10.07 (\underline{A}_{e454} + \underline{A}_{e460}) \frac{\underline{N}_{s454//460}}{\sqrt{T_3}} (\underline{P}_{12 \text{ GH}_2} - 0.0977 \dot{W}_{12 \text{ GH}_2}^2)$$

(9) Equations:

$$(a) \dot{P}_{13 \text{ GH}_2} = 0.223 T_3 (\dot{W}_{12 \text{ GH}_2} - \dot{W}_{13 \text{ GH}_2})$$

$$(b) P_{13 \text{ GH}_2} = \int_0^t \dot{P}_{13 \text{ GH}_2} dt + P_{13} (\text{I.C.})$$

Maxima:

$$\dot{P}_{13 \text{ GH}_2} = 2500 \text{ psia/sec}$$

$$P_{13 \text{ GH}_2} = 2500 \text{ psia}$$

$$T_3 = 560^\circ \text{R}$$

$$\dot{W}_{12 \text{ GH}_2} = \dot{W}_{13 \text{ GH}_2} = 50 \text{ lb/sec}$$

Scaled Equations:

$$2500 \dot{P}_{13 \text{ GH}_2} = (0.223) (560) T_3 (50 \dot{W}_{12 \text{ GH}_2} - 50 \dot{W}_{13 \text{ GH}_2})$$

$$(a) \dot{P}_{13 \text{ GH}_2} = 2.50 T_3 (\dot{W}_{12 \text{ GH}_2} - \dot{W}_{13 \text{ GH}_2})$$

$$2500 P_{13 \text{ GH}_2} = \int_0^t \dot{P}_{13 \text{ GH}_2} dt + P_{13} \text{ (I.C.)}$$

$$(b) P_{13 \text{ GH}_2} = \int_0^t \dot{P}_{13 \text{ GH}_2} dt + \frac{P_{13 \text{ GH}_2} \text{ (I.C.)}}{2500}$$

(10) Equations:

$$(a) \dot{W}_{13 \text{ GH}_2} = 0.1402 A_{\text{ecdsv}} \frac{N_{\text{scdsv}}}{\sqrt{T_3}} (P_{13 \text{ GH}_2} - 0.1037 \dot{W}_{13 \text{ GH}_2}^2)$$

$$(b) \dot{W}_{13 \text{ GH}_2} \geq 0 \text{ (CDCHV)}$$

Maxima:

$$\dot{W}_{13 \text{ GH}_2} = 50 \text{ lb/sec}$$

$$A_{\text{ecdsv}} = 30 \text{ in.}^2$$

$$N_{\text{scdsv}} = 1$$

$$T_3 = 560^\circ\text{R}$$

$$P_{13 \text{ GH}_2} = 2500 \text{ psia}$$

Scaled Equation:

$$50 \dot{W}_{13 \text{ GH}_2} = (0.1402)(30)(1) \frac{A_{\text{ecdsv}} N_{\text{scdsv}}}{\sqrt{560} \sqrt{T_3}} (2500 P_{13 \text{ GH}_2} - 0.1037)$$

$$(50^2) \dot{W}_{13 \text{ GH}_2}^2$$

$$\dot{W}_{13 \text{ GH}_2} = 8.90 \frac{A_{\text{ecdsv}} N_{\text{scdsv}}}{\sqrt{560} \sqrt{T_3}} (P_{13 \text{ GH}_2} - 0.1037 \dot{W}_{13 \text{ GH}_2}^2) / \sqrt{T_3}$$

(11) Equation:

$$N_{\text{scdsv}} = f \left(\frac{P_{13 \text{ GH}_2} - 0.1037 \dot{W}_{13 \text{ GH}_2}^2 - P_{e3}}{P_{13 \text{ GH}_2} - 0.1037 \dot{W}_{13 \text{ GH}_2}^2} \right)$$

Maxima:

$$N_{\text{scdsv}} = 1$$

$$P_{13 \text{ GH}_2} = 2500 \text{ psia}$$

$$P_{e3} = 1000 \text{ psia}$$

$$\dot{W}_{13 \text{ GH}_2} = 50 \text{ lb/sec}$$

Scaled Equation:

$$(1) \quad \underline{N}_{\text{scdsv}} = f \left(\frac{2500 \underline{P}_{13} \text{ GH}_2 - 0.1037 (50)^2 \underline{W}_{13}^2 \text{ GH}_2 - 1000 \underline{P}_{e3}}{\underline{P}_{13} \text{ GH}_2 - 0.1037 (50)^2 \underline{W}_{13}^2 \text{ GH}_2} \right)$$

$$\underline{N}_{\text{scdsv}} = f \left(\frac{\underline{P}_{13} \text{ GH}_2 - 0.1037 \underline{W}_{13}^2 \text{ GH}_2 - 0.4 \underline{P}_{e3}}{\underline{P}_{13} \text{ GH}_2 - 0.1037 \underline{W}_{13}^2 \text{ GH}_2} \right)$$

(12) Equation:

$$\underline{N}_{s201} = f \left(\frac{\underline{P}_7 - \underline{P}_8}{\underline{P}_7} \right)$$

Maxima:

$$\underline{N}_{s201} = 1$$

$$\underline{P}_7 = \underline{P}_8 = 2500 \text{ psia}$$

Scaled Equation:

$$(1) \quad \underline{N}_{s201} = f \left(\frac{2500 \underline{P}_7 - 2500 \underline{P}_8}{2500 \underline{P}_7} \right)$$

$$\underline{N}_{s201} = f \left(\frac{\underline{P}_7 - \underline{P}_8}{\underline{P}_7} \right)$$

(13) Equation:

$$N_{s251} = f\left(\frac{P_8 - 0.1812 \dot{W}_8^2 - P_{14}}{P_8 - 0.1812 \dot{W}_8^2}\right)$$

Maxima:

$$N_{s251} = 1$$

$$P_8 = P_{14} = 2500 \text{ psia}$$

$$\dot{W}_8 = 50 \text{ lb/sec}$$

Scaled Equation:

$$(1) \quad \underline{N}_{s251} = f\left(\frac{2500 \underline{P}_8 - 0.1812 (50)^2 \underline{\dot{W}}_8^2 - 2500 \underline{P}_{14}}{2500 \underline{P}_8 - 0.1812 (50)^2 \underline{\dot{W}}_8^2}\right)$$

$$\underline{N}_{s251} = f\left(\frac{\underline{P}_8 - 0.1812 \underline{\dot{W}}_8^2 - \underline{P}_{14}}{\underline{P}_8 - 0.1812 \underline{\dot{W}}_8^2}\right)$$

(14) Equation:

$$N_{s\ 454//460} = f\left(\frac{P_{12\ GH_2} - 0.0977 \dot{W}_{12\ GH_2}^2 - P_{13\ GH_2}}{P_{12\ GH_2} - 0.0977 \dot{W}_{12\ GH_2}^2}\right)$$

Maxima:

$$N_{s454//460} = 1$$

$$P_{12\ GH_2} = P_{13\ GH_2} \quad 2500 \text{ psia}$$

$$\dot{W}_{12\ GH_2} = 50 \text{ lb/sec}$$

Scaled Equation:

$$(1) \quad \frac{N_{s454//460}}{1} = f\left(\frac{2500 \frac{P_{12\ GH_2}}{2500} - 0.0977 (50)^2 \frac{\dot{W}_{12\ GH_2}^2}{50^2} - 2500 \frac{P_{13\ GH_2}}{2500}}{2500 \frac{P_{12\ GH_2}}{2500} - 0.0977 (50)^2 \frac{\dot{W}_{12\ GH_2}^2}{50^2}}\right)$$

$$\frac{N_{s454//460}}{1} = f\left(\frac{\frac{P_{12\ GH_2}}{2500} - 0.0977 \frac{\dot{W}_{12\ GH_2}^2}{50^2} - \frac{P_{13\ GH_2}}{2500}}{\frac{P_{12\ GH_2}}{2500} - 0.0977 \frac{\dot{W}_{12\ GH_2}^2}{50^2}}\right)$$

3.2.3.3.2.2 LH₂ Scaled Equations

(1a) Equation: $P_9 = P_9(0) = 1000$

Maxima:

$$P_9 = 1000$$

Scaled Equation:

$$1000 \underline{P}_9 = 1000$$

$$\boxed{\underline{P}_9 = 1.0}$$

(1b) Equation: $T_4 = T_4(0) = 37^\circ\text{R}$

Maxima:

$$T_4 = 37^\circ\text{R} \quad \text{Scale to } 50^\circ\text{R}$$

Scaled Equation:

$$\underline{T}_4 = \frac{37}{50} = 0.74$$

$$\boxed{\underline{T}_4 = 0.74}$$

(2) Equation: $\dot{W}_9 = .738 A_{e\ 107} (P_9 - P_{10})^{1/2}$

Maxima:

$$\dot{W}_9 = 50 \text{ \#/sec}$$

$$A_{e\ 107} = 29 \text{ in}^2$$

$$P_9 = 1000 \text{ psia}$$

Scaled Equation:

$$50 \dot{W}_9 = (.738)(29)(A_{e\ 107})(1000)^{1/2}(P_9 - P_{10})^{1/2}$$

$$\dot{W}_9 = \frac{(.738)(29)(31.6)}{50} A_{e\ 107} (P_9 - P_{10})^{1/2}$$

$$\dot{W}_9 = 13.53 A_{e\ 107} (P_9 - P_{10})^{1/2}$$

(3) Equations: (a) $\dot{P}_{10} = 126 (\dot{W}_9 - \dot{W}_{10})$

$$P_{10} = \int_0^t \dot{P}_{10} dt + P_{10} \text{ (I.C.)}$$

Maxima:

$$\dot{W}_9 = \dot{W}_{10} = 50 \text{ lb/sec}$$

$$\dot{P}_{10} = 1000 \text{ psi/sec}$$

$$P_{10} = 1000 \text{ psia}$$

Scaled Equations:

$$1000 \dot{\underline{P}}_{10} = 126 (50 \dot{\underline{W}}_9 - 50 \dot{\underline{W}}_{10})$$

$$(a) \boxed{\dot{\underline{P}}_{10} = 6.3 (\dot{\underline{W}}_9 - \dot{\underline{W}}_{10})}$$

$$1000 \dot{\underline{P}}_{10} = \int_0^t 1000 \dot{\underline{P}}_{10} dt + P_{10} \text{ (I.C.)}$$

$$(b) \boxed{\underline{P}_{10} = \int_0^t \dot{\underline{P}}_{10} dt + \frac{P_{10} \text{ (I.C.)}}{1000}}$$

(4) Equations: (a) $\ddot{W}_{10} = 9.92 (P_{10} - 0.0054 \dot{W}_{10}^2 - P_{11})$

(b) $\dot{W}_{10} = \int_0^t \ddot{W}_{10} dt$

Maxima:

$$\ddot{W}_{10} = 100 \text{ lb/sec}^2$$

$$\dot{W}_{10} = 50 \text{ lb/sec}$$

$$P_{10} = P_{11} = 1000 \text{ psia}$$

Scaled Equations:

$$100 \ddot{W}_{10} = 9.92 [1000 \underline{P}_{10} - 0.0054 (50)^2 \dot{W}_{10}^2 - 1000 \underline{P}_{11}]$$

$$\ddot{W}_{10} = 9.92 [10 (\underline{P}_{10} - \underline{P}_{11}) - 0.14 \dot{W}_{10}^2]$$

$$(a) \boxed{\ddot{W}_{10} = 99.2 [(\underline{P}_{10} - \underline{P}_{11}) - 0.014 \dot{W}_{10}^2]}$$

$$50 \dot{W}_{10} = \int_0^t 100 \ddot{W}_{10} dt$$

$$(b) \boxed{\dot{W}_{10} = 2 \int_0^t \ddot{W}_{10} dt}$$

(5) Equations: (a) $\dot{P}_{11} = 126 (\dot{W}_{10} - \dot{W}_{11})$

(b) $P_{11} = \int_0^t P_{11} dt + P_{11} \text{ (I.C.)}$

Maxima:

$\dot{W}_{10} = \dot{W}_{11} = 50 \text{ lb/sec}$

$\dot{P}_{11} = 1000 \text{ psi/sec}$

$P_{11} = 1000 \text{ psia}$

Scaled Equations:

$1000 \dot{\underline{P}}_{11} = 126 (50 \dot{\underline{W}}_{10} - 50 \dot{\underline{W}}_{11})$

(a) $\boxed{\dot{\underline{P}}_{11} = 6.3 (\dot{\underline{W}}_{10} - \dot{\underline{W}}_{11})}$

$1000 \underline{P}_{11} = \int_0^t 1000 \dot{\underline{P}}_{11} dt + P_{11} \text{ (I.C.)}$

(b) $\boxed{\underline{P}_{11} = \int_0^t \dot{\underline{P}}_{11} dt + \frac{P_{11} \text{ (I.C.)}}{1000}}$

(6) Equation: $\dot{W}_{11} = .74 A_{e\ 472} (P_{11} - P_{15})^{1/2}$

Maxima:

$$\dot{W}_{11} = 50 \text{ lb/sec}$$

$$A_{e\ 472} = 6.5 \text{ in}^2$$

$$P_{11} = 1000 \text{ psia}$$

Scaled Equation:

$$50 \dot{W}_{11} = (.74)(6.5) A_{e\ 472} (1000 P_{11} - 1000 P_{15})^{1/2}$$

$$\dot{W}_{11} = 3.04 A_{e\ 472} (P_{11} - P_{15})^{1/2}$$

(7) Equations: (a) $\dot{P}_{15} = 1036 (\dot{W}_{11} - \dot{W}_{14})$

(b) $P_{15} = \int_0^t \dot{P}_{15} dt + P_{15} \text{ (I.C.)}$

Maxima:

$\dot{P}_{15} = 1500 \text{ psi/sec}$

$P_{15} = 1000 \text{ psia}$

$\dot{W}_{11} = \dot{W}_{14} = 50 \text{ lb/sec}$

Scaled Equations:

$1500 \dot{\underline{P}}_{15} = 1036 (50 \dot{\underline{W}}_{11} - 50 \dot{\underline{W}}_{14})$

(a) $\boxed{\dot{\underline{P}}_{15} = 34.5 (\dot{\underline{W}}_{11} - \dot{\underline{W}}_{14})}$

$1000 \underline{P}_{15} = \int_0^t 1500 \dot{\underline{P}}_{15} dt + P_{15} \text{ (I.C.)}$

(b) $\boxed{\underline{P}_{15} = 1.5 \int_0^t \dot{\underline{P}}_{15} dt + \frac{P_{15} \text{ (I.C.)}}{1000}}$

(8) Equation: $\dot{W}_{14} = 0.75 (A_{e\ 458} + A_{e\ 459}) (P_{15} - P_{13} - 0.0036 \dot{W}_{14}^2)$

Maxima:

$$A_{e\ 458} = A_{e\ 459} = 31.22 \text{ in.}^2$$

$$P_{15} = 1000 \text{ psia}$$

$$P_{13} = 1000 \text{ psia}$$

$$\dot{W}_{14} = 50 \text{ lb/sec}$$

Scaled Equation:

$$50 \dot{W}_{14} = (0.75)(31.22 \underline{A}_{e\ 458} + 31.22 \underline{A}_{e\ 459}) (1000 \underline{P}_{15} - 1000 \underline{P}_{13} - 0.0036 (50)^2 \dot{W}_{14}^2)^{1/2}$$

$$\dot{W}_{14} = \frac{(0.75)(31.22)(1000)^{1/2}}{(50)} (\underline{A}_{e\ 458} + \underline{A}_{e\ 459}) (\underline{P}_{15} - 1.0 \underline{P}_{13} - 0.09 \dot{W}_{14}^2)^{1/2}$$

$$\boxed{\dot{W}_{14} = 14.8 (\underline{A}_{e\ 458} + \underline{A}_{e\ 459}) (\underline{P}_{15} - 1.0 \underline{P}_{13} - 0.0900 \dot{W}_{14}^2)^{1/2}}$$

(9) Equations: (a) $\dot{P}_{13LH_2} = 80.0 (\dot{W}_{14} - \dot{W}_{16LH_2})$

(b) $P_{13LH_2} = \int_0^t \dot{P}_{13LH_2} dt + P_{13LH_2} \text{ (I.C.)}$

Maxima:

$$P_{13LH_2} = 1000 \text{ psia}$$

$$\dot{P}_{13LH_2} = 1000 \text{ psi/sec}$$

$$\dot{W}_{14} = 50 \text{ lb/sec}$$

$$\dot{W}_{16LH_2} = 50 \text{ lb/sec}$$

Scaled Equations:

$$1000 \dot{P}_{13LH_2} = 80.0 (50 \dot{W}_{14} - 50 \dot{W}_{16LH_2})$$

(a) $\boxed{\dot{P}_{13LH_2} = 4.0 (\dot{W}_{14} - \dot{W}_{16LH_2})}$

$$1000 P_{13LH_2} = \int_0^t \dot{P}_{13LH_2} dt + P_{13LH_2} \text{ (I.C.)}$$

(b) $\boxed{P_{13LH_2} = \int_0^t \dot{P}_{13LH_2} dt + \frac{P_{13LH_2} \text{ (I.C.)}}{1000}}$

(10) Equations: (a) $\ddot{w}_{16LH_2} = 7.0 (P_{13LH_2} - 0.0234 \dot{w}_{16LH_2}^2) - P_{16LH_2}$

(b) $\dot{w}_{16LH_2} = \int_0^t \ddot{w}_{16LH_2} dt$

Maxima:

$\dot{w}_{16LH_2} = 50 \text{ lb/sec}$

$\ddot{w}_{16LH_2} = 1000 \text{ lb/sec}^2$

$P_{13LH_2} = 1000 \text{ psia}$

$P_{16LH_2} = 1000 \text{ psia}$

Scaled Equations:

$1000 \ddot{w}_{16LH_2} = (7.0) (1000 P_{13LH_2} - 1000 P_{16LH_2} - 0.0234 \times 50^2 \dot{w}_{16LH_2}^2)$

(a) $\ddot{w}_{16LH_2} = 7.0 (P_{13LH_2} - P_{16LH_2} - 0.0585 \dot{w}_{16LH_2}^2)$

$50 \dot{w}_{16LH_2} = \int_0^t 1000 \ddot{w}_{16LH_2} dt$

(b) $\dot{w}_{16LH_2} = 20 \int_0^t \ddot{w}_{16LH_2} dt$

(11) Equations:

(a) $\dot{P}_{16LH_2} = 80 (\dot{W}_{16LH_2} - \dot{W}_{13LH_2})$

(b) $P_{16LH_2} = \int_0^t \dot{P}_{16LH_2} dt + P_{16LH_2} (I.C.)$

Maxima:

$$P_{16LH_2} = 1000 \text{ psia}$$

$$\dot{P}_{16LH_2} = 1000 \text{ psi/sec}$$

$$\dot{W}_{16LH_2} = \dot{W}_{13LH_2} = 50 \text{ lb/sec}$$

Scaled Equations:

$$1000 \dot{\underline{P}}_{16LH_2} = 80.0 (50 \dot{\underline{W}}_{16LH_2} - 50 \dot{\underline{W}}_{13LH_2})$$

(a) $\boxed{\dot{\underline{P}}_{16LH_2} = 4.0 (\dot{\underline{W}}_{16LH_2} - \dot{\underline{W}}_{13LH_2})}$

$$1000 \underline{P}_{16LH_2} = \int_0^t 1000 \dot{\underline{P}}_{16LH_2} dt + P_{16LH_2} (I.C.)$$

(b) $\boxed{\underline{P}_{16LH_2} = \int_0^t \dot{\underline{P}}_{16LH_2} dt + \frac{P_{16LH_2} (I.C.)}{1000}}$

(12) Equations: (a) $\dot{W}_{13LH_2} = 1.167 A_{e\ CDSV} (P_{16LH_2} - P_{e3})^{1/2}$

(b) $\dot{W}_{13LH_2} \geq 0$

Maxima:

$\dot{W}_{13LH_2} = 50 \text{ lb/sec}$

$A_{eCDSV} = 1000 \text{ psia}$

$P_{16LH_2} = 1000 \text{ psia}$

$P_{e3} = 1000 \text{ psia}$

Scaled Equation:

$50 \dot{W}_{13LH_2} = (1.167) (30) \underline{A}_{e\ CDSV} (1000 \underline{P}_{16LH_2} - 1000 \underline{P}_{e3})^{1/2}$

(a) $\boxed{\dot{W}_{13LH_2} = 22.10 (1.0 \underline{P}_{16LH_2} - \underline{P}_{e3})^{1/2} \underline{A}_{eCDSV}}$

3.2.3.3.2.3 LN₂ Scaled Equations

(1) Equations: (a) $P_1 = P_1(0) = 250 \text{ psia}$

(b) $T_1 = T_1(0) = 202^\circ\text{R}$

Maxima:

$$P_1 = 250 \text{ psia}$$

$$T_1 = 202^\circ\text{R}$$

Scaled Equations:

$$250 \frac{P}{P_1} = 250$$

(a) $\boxed{\frac{P}{P_1} = 1}$

$$202 \frac{T}{T_1} = 202$$

(b) $\boxed{\frac{T}{T_1} = 1}$

(2) Equations: (a) $\ddot{w}_1 = 3.34 (P_1 - 0.00194 \dot{w}_1^2 - P_2)$

(b) $\dot{w}_1 = \int_0^t \ddot{w}_1 dt$

Maxima:

$$\ddot{w}_1 = 5000 \text{ lb/sec}^2$$

$$w_1 = 100 \text{ lb/sec}$$

$$P_1 = P_2 = 250 \text{ psia}$$

Scaled Equations:

$$5000 \ddot{\underline{w}}_1 = (3.34) [250 \underline{P}_1 - 0.00194 (100)^2 \dot{\underline{w}}_1^2 - 250 \underline{P}_2]$$

$$\ddot{\underline{w}}_1 = .167 [\underline{P}_1 - 0.0766 \dot{\underline{w}}_1^2 - \underline{P}_2]$$

Substituting (20)a: $\underline{P}_1 = 1$

$$(a) \quad \ddot{\underline{w}}_1 = 0.167 [1 - 0.0766 \dot{\underline{w}}_1^2 - \underline{P}_2]$$

$$100 \dot{\underline{w}}_1 = \int_0^t 5000 \ddot{\underline{w}}_1 dt$$

$$(b) \quad \dot{\underline{w}}_1 = 50 \int_0^t \ddot{\underline{w}}_1 dt$$

(3) Equations: (a) $\dot{P}_2 = 20.5 (\dot{w}_1 - \dot{w}_2)$

(b) $P_2 = \int_0^t P_2 dt + P_2 \text{ (I.C.)}$

Maxima:

$$\dot{P}_2 = 2500 \text{ psia/sec}$$

$$P_2 = 250 \text{ psia}$$

$$\dot{w}_1 = \dot{w}_2 = 100 \text{ lb/sec}$$

Scaled Equations:

$$2500 \dot{\underline{P}}_2 = 20.5 (100 \dot{\underline{w}}_1 - 100 \dot{\underline{w}}_2)$$

(a) $\boxed{\dot{\underline{P}}_2 = 0.82 (\dot{\underline{w}}_1 - \dot{\underline{w}}_2)}$

$$250 \underline{P}_2 = \int_0^t 2500 \dot{\underline{P}}_2 dt + P_2 \text{ (I.C.)} \quad [P_2 \text{ (I.C.)} \equiv 250]$$

(b) $\boxed{\underline{P}_2 = 10 \int_0^t \dot{\underline{P}}_2 dt + 1}$

(4) Equation: $\dot{w}_2 = 2.175 A_{e517} (P_2 - P_3)^{1/2}$

Maxima:

$$\dot{w}_2 = 100 \text{ lb/sec}$$

$$A_{e517} = 6.25 \text{ in}^2$$

$$P_2 = P_3 = 250 \text{ psia}$$

Scaled Equation:

$$100 \dot{w}_2 = (2.175) (6.25) A_{e517} (250 P_2 - 250 P_3)^{1/2}$$

$$\boxed{\dot{w}_2 = 2.15 A_{e517} (P_2 - P_3)^{1/2}}$$

(5) Equations: (a) $\dot{P}_3 = 42.2 \dot{w}_2 - \dot{w}_3$

(b) $\dot{P}_3 = \int_0^t P_3 dt + P_3 \text{ (I.C.)}$

Maxima:

$$\dot{P}_3 = 2500 \text{ psia/sec}$$

$$P_3 = 250 \text{ psia}$$

$$\dot{w}_2 = \dot{w}_3 = 100 \text{ lb/sec}$$

Scaled Equations:

$$2500 \dot{\underline{P}}_3 = (42.2) (100 \dot{\underline{w}}_2 - 100 \dot{\underline{w}}_3)$$

(a) $\dot{\underline{P}}_3 = 1.685 (\dot{\underline{w}}_2 - \dot{\underline{w}}_3)$

$$250 \underline{P}_3 = \int_0^t 2500 \dot{\underline{P}}_3 dt + P_3 \text{ (I.C.)}$$

(b) $\underline{P}_3 = 10 \int_0^t \dot{\underline{P}}_3 dt + \frac{P_3 \text{ (I.C.)}}{250}$

(6) Equation: $\dot{w}_3 = 2.18 A_{e545} (P_3 - P_{13LN_2} - 0.00126 \dot{w}_3^2)^{1/2}$

Maxima:

$$\dot{w}_3 = 100 \text{ lb/sec}$$

$$A_{e545} = 31.22 \text{ in}^2$$

$$P_3 = 250 \text{ psia}$$

$$P_{13LN_2} = 250 \text{ psia}$$

Scaled Equation:

$$100 \dot{w}_3 = (2.18) (31.22) A_{e545} (250 P_3 - 250 P_{13LN_2} - 0.00126 (100)^2 \dot{w}_3^2)^{1/2}$$

$$\dot{w}_3 = 10.75 A_{e545} (P_3 - P_{13LN_2} - 0.054 \dot{w}_3^2)^{1/2}$$

$$\dot{w}_3^2)^{1/2}$$

(7) Equations: (a) $\dot{P}_{13LN_2} = 80 (\dot{w}_3 - \dot{w}_{16LN_2})$

(b) $P_{13LN_2} = \int_0^t \dot{P}_{13LN_2} dt + P_{13} \text{ (I.C.)}$

Maxima:

$$\dot{P}_{13LN_2} = 5000 \text{ psia/sec}$$

$$P_{13LN_2} = 250 \text{ psia}$$

$$\dot{w}_3 = \dot{w}_{16LN_2} = 100 \text{ lb/sec}$$

Scaled Equations:

$$5000 \dot{\underline{P}}_{13LN_2} = 80 (100 \dot{\underline{w}}_3 - 100 \dot{\underline{w}}_{16LN_2})$$

$$(a) \boxed{\dot{\underline{P}}_{13LN_2} = 1.6 (\dot{\underline{w}}_3 - \dot{\underline{w}}_{16LN_2})}$$

$$250 \underline{P}_{13LN_2} = \int_0^t 5000 \dot{\underline{P}}_{13LN_2} dt + P_{13} \text{ (I.C.)}$$

$$(b) \boxed{\underline{P}_{13LN_2} = 20 \int_0^t \dot{\underline{P}}_{13LN_2} dt + \frac{P_{13} \text{ (I.C.)}}{2500}}$$

(8) Equations: (a) $\ddot{w}_{16LN_2} = 40.1 (P_{13LN_2} - 0.0093 \dot{w}_{16LN_2} - P_{16LN_2})$

(b) $\dot{w}_{16LN_2} = \int_0^t \ddot{w}_{16LN_2} dt$

Maxima:

$$\ddot{w}_{16LN_2} = 10^4 \text{ lb/sec}^2$$

$$\dot{w}_{16LN_2} = 100 \text{ lb/sec}$$

$$P_{13LN_2} = 250 \text{ psia}$$

$$P_{16LN_2} = 250 \text{ psia}$$

Scaled Equation:

$$10^4 \ddot{\underline{w}}_{16LN_2} = 40.1 (250 \underline{P}_{13LN_2} - 0.0093 (100)^2 \dot{\underline{w}}_{16LN_2}^2 - 250 \underline{P}_{16LN_2})$$

(a) $\ddot{\underline{w}}_{16LN_2} = .1002 (\underline{P}_{13LN_2} - 0.372 \dot{\underline{w}}_{16LN_2}^2 - \underline{P}_{16LN_2})$

$$100 \dot{\underline{w}}_{16LN_2} = \int 10^4 \ddot{\underline{w}}_{16LN_2} dt$$

(b) $\dot{\underline{w}}_{16LN_2} = 100 \int_0^t \ddot{\underline{w}}_{16LN_2} dt$

(9) Equations: (a) $\dot{P}_{16LN_2} = 80 (\dot{w}_{16LN_2} - \dot{w}_{13LN_2})$

(b) $P_{16LN_2} = \int_0^t \dot{P}_{16LN_2} dt + P_{16LN_2} \text{ (I.C.)}$

MAXIMA:

$\dot{P}_{16LN_2} = 5000 \text{ psia/sec}$

$P_{16LN_2} = 250 \text{ psia}$

$\dot{w}_{16LN_2} = \dot{w}_{13LN_2} = 100 \text{ lb/sec}$

Scaled Equations:

$5000 \dot{\underline{P}}_{16LN_2} = 80 (100 \dot{\underline{w}}_{16LN_2} - 100 \dot{\underline{w}}_{13LN_2})$

(a) $\boxed{\dot{\underline{P}}_{16LN_2} = 1.6 (\dot{\underline{w}}_{16LN_2} - \dot{\underline{w}}_{13LN_2})}$

$250 \underline{P}_{16LN_2} = \int_0^t 5000 \dot{\underline{P}}_{16LN_2} dt + P_{16LN_2} \text{ (I.C.)}$

(b) $\boxed{\underline{P}_{16LN_2} = 20 \int_0^t \dot{\underline{P}}_{16LN_2} dt + \frac{P_{16LN_2} \text{ (I.C.)}}{250}}$

(10) Equation: (a) $\dot{w}_{13LN_2} = 3.0 A_{ecDSV} (P_{16LN_2} - P_{e3})^{1/2}$

(b) $\dot{w}_{13LN_2} \geq 0 \text{ (CDCHV)}$

MAXIMA:

$$\dot{w}_{13LN_2} = 100 \text{ lb/sec}$$

$$A_{eCDSV} = 30 \text{ in.}^2$$

$$P_{16LN_2} = 250 \text{ psia}$$

$$P_{e3} = 1000 \text{ psia}$$

Scaled Equation:

$$100 \dot{w}_{13LN_2} = (3.0) (30) A_{eCDSV} (250 P_{16LN_2} - 1000 P_{e3})^{1/2}$$

$$\dot{w}_{13LN_2} = 2.846 A_{eCDSV} (.250 P_{16LN_2} - P_{e3})^{1/2}$$

3.2.3.3.3 Procedure

3.2.3.3.3.1 Liquid Control Functional Group

- a. Verify that all power supply voltages are at their proper values.
- b. Verify that all the amplifiers are properly balanced.
- c. Select the appropriate control group for the type of liquid to be simulated.
- d. Verify the potentiometer gains are the same as on AGC Drawing 1114289. To set or change potentiometers see section 2.4.1.3.
- e. Verify the DFG's output, refer to section 2.4.1.2.
- f. To set or change the RSV actuator simulation see section 2.4.1.5.

3.2.3.3.3.2 Liquid Feed Functional Group

- a. Verify that all power supply voltages are at their proper values.
- b. Verify that all the amplifiers are properly balanced.
- c. Select the appropriate feed group for the type of liquid to be simulated.

d. Verify the potentiometer gains are the same as on AGC Drawing 1114289. To set or change potentiometers see section 2.4.1.3.

e. Verify the DFG's output, refer to section 2.4.1.2.

f. To set or change the RSV actuator simulation see section 2.4.1.5.

3.2.3.3.3.3 Gas Control Functional Group

a. Verify that all power supplies voltages are at their proper values.

b. Verify that all amplifiers are properly balanced.

c. Select the appropriate control group for the type of gas to be simulated.

d. Verify the potentiometer gains are the same as on AGC Drawing 1114289. To set or change potentiometers see section 2.4.1.3.

e. Verify the DFG's output, refer to section 2.4.1.2.

f. To set or change the RSV actuator simulator see section 2.4.1.5.

3.2.3.3.3.4 Gas Feed Functional Group

a. Verify that all power supplies voltages are at their proper values.

b. Verify that all amplifiers are properly balanced.

c. Select the appropriate feed group for the type of gas to be simulated.

d. Verify the potentiometer gains are the same as on AGC Drawing 1114289. To set or change potentiometers see section 2.4.1.3.

e. Verify the DFG's output, refer to section 2.4.1.2.

f. To set or change the RSV actuator simulation see section 2.4.1.5.

3.2.3.3.3.5 Gas Manifold Functional Group

a. Verify that all power supply voltages are at their proper values.

b. Verify that all amplifiers are properly balanced.

c. Select the appropriate gas manifold for the type of gas to be simulated.

d. Verify the potentiometer gains are the same as on AGC Drawing 1114289. To set or change potentiometers see section 2.4.1.3.

e. Verify the DFG's output, refer to section 2.4.1.2.

f. To set or change the RSV actuator simulation see section 2.4.1.5.

3.2.3.3.4 Operational Check

3.2.3.3.4.1 Liquid Control Functional Group

Essentially there are only two dynamic checks in addition to the standard static check that can be made to verify the circuit operation. These are an RSV step operation and a system transfer function check.

The diode function generators can be conveniently checked using figures 16 and 17 during a static check or separately in the DFG set-up slot.

3.2.3.3.4.2 Liquid Feed Function Group

Same as section 3.2.3.3.4.1.

3.2.3.3.4.3 Gas Control Functional Group

Same as section 3.2.3.3.4.1.

3.2.3.3.4.4 Gas Feed Functional Group

Same as section 3.2.3.3.4.1.

3.2.3.3.4.5 Gas Manifold Functional Group

Same as section 3.2.3.3.4.1.

3.2.3.3.4.6 Common Manifold Functional Group

Same as section 3.2.3.3.4.1.

(a)		(b)	
L_{PCV}	A_{PCV}	L_{PCV}	A_{ePCV}
%	%	%	%
0	0.0	0.0	0.0
10	2.5	5.0	3.2
20	6.0	10.0	6.0
30	10.0	15.0	9.2
40	15.0	20.0	12.0
50	22.0	25.0	14.0
60	32.0	30.0	17.4
70	48.0	35.0	19.6
80	72.0	40.0	22.5
85	82.0	45.0	26.0
90	91.0	50.0	30.0
100	100.0	55.0	35.0
		60.0	40.0
		65.0	45.6
		70.0	52.0
		75.0	59.0
		80.0	68.0
		85.0	78.0
		90.0	86.0
		95.0	94.0
		100.0	100.0

Figure 16 - PCV Area Versus Lift Curve

DFG SET UP POINTS			
INPUT L _{RSV} %	OUTPUT A _{eRSV} %	SLOPE	BREAK POINT
0.00	0.00	PARALLAX	---
4.50 (CRITICAL)	1.80 (CRITICAL)	CS	1
14.50	11.25	1	2
19.00	20.50 (MAXIMUM)	2	3
25.00	36.70 (MAXIMUM)	3	4
30.00	58.12 (MAXIMUM)	4	5
31.00	62.40 (MINIMUM)	5	6
32.50	69.15 (MINIMUM)	6	7
38.00	80.00 (MINIMUM)	7	8
50.00	90.00	8	9
70.00	96.00	9	10
100.00	100.00	10	---

Figure 17 - RSV Area Versus Lift Curve

3.2.3.4 Cooldown Variable Breakpoint Function Generator Settings

3.2.3.4.1 General

The variable Breakpoint Function Generators in the Cooldown Network are set up according to the tables and curves of the Figures in Section 3.4.2. (Reference Section 2.4.1.2, "DFG Set-up Procedures").

3.2.3.4.2 Empirical Relationships of Cooldown Variables

- a. PCV Area vs. Lift Curve (Figure 16)
- b. RSV Area vs. Lift Curve (Figure 17)
- c. CSV Area vs. Angle Curve (Figure 18)
- d. GHe Source Temperature Curve (Figure 19)
- e. GHe Source Pressure Curve (Figure 20)

$\theta_{CSV} / \theta_{MAX CSV}$	$A_{eCSV} / A_{e MAX CSV}$
%	%
0.00	0.00
15.00	2.10
20.00	3.00
25.00	4.00
30.00	5.40
35.00	6.80
40.00	8.40
45.00	10.50
50.00	12.90
55.00	16.00
60.00	19.60
65.00	24.80
70.00	31.00
75.00	38.80
80.00	49.10
85.00	61.20
90.00	76.40
95.00	92.30
97.20	100.00
98.30	100.00
100.00	95.90

Figure 18 - CSV Area Versus Angle Curve

$$f(\dot{W}_4) T_2 = [f(\dot{W}_4)]^{0.67}$$

%	%
0	0.00
2	7.32
5	13.43
10	21.27
15	27.94
20	33.95
25	39.50
30	44.70
35	49.40
40	54.00
45	58.50
50	62.85
55	66.68
60	70.80
65	75.00
70	78.80
75	82.30
80	86.10
85	89.55
90	93.30
95	96.60
100	100.00

Figure 19 - GHe Source Temperature Curve

$f(\dot{W}_4)$ %	$P_4 = [f(\dot{W}_4)]^{1.67}$ %
0	0.0
2	--
5	6.679
10	2.15
15	4.22
20	6.84
25	9.85
30	13.2
35	14.8
40	20.0
45	26.2
50	31.2
55	36.6
60	42.3
65	47.1
70	54.8
75	61.8
80	68.6
85	75.6
90	83.2
95	90.4
100	100.0

Figure 20 - GHe Source Pressure Curve

4. MAINTENANCE AND TROUBLESHOOTING

GENERAL

The maintenance of the equipment shall be carried out as outlined in the service manuals provided with the equipment. Under normal operating conditions, the equipment is relatively maintenance free. Since there is very little heat produced in the equipment, there is little tendency for the power supplies to drift. The reference power supply voltage should be checked on a periodic basis, in any case, to determine any drift. This can be done from the front of the console using the Digital Voltmeter. If the power supplies require balancing, then set up Box No. 2.489 can be used to easily balance the equipment.

4.1 TROUBLESHOOTING

Troubleshooting the equipment should be carried out similar to the method used in troubleshooting a general purpose analog computer. This normally involves a systematic voltage search by measuring the outputs of amplifiers, potentiometers and other components of the system. Caution should be taken whenever making voltage readings until one is very familiar with the equipment.

In the case where steady state values are given at IC and 100% power conditions such as the Engine Simulation, it usually is not too difficult to find the source of trouble since the problem area usually is distinguishable by an appreciable change in voltage.

In any troubleshooting situation, however, it is important for the person doing the troubleshooting to have a "feel" for the system. It is imperative therefore, that the person assigned to the TSS be intimately familiar with the theory and operation of the simulation.

4.1.1 Probable Trouble Areas

Following is a list of probable trouble areas as were experienced during checkout of the equipment at Sacramento:

- (1) Bad Zener Diode
- (2) Bad Computing Resistors
- (3) Poor solder connection (usually inside network can)
- (4) Broken wire at solder joint (usually inside network can)
- (5) Network can or amplifier not pushed in rack far enough, thereby making a poor connection on the blue ribbon connector.
- (6) Burned out relay.

4.1.2 Suggestions to Aid in Troubleshooting

A quick way to investigate trouble areas is to check the overload lights which are plugged into the front of various amplifiers throughout the system. A bright overload light should be investigated for possible malfunction. In addition, each amplifier has in its output stage, two incandescent lamps which are connected in series with each emitter. The purpose of the lamps is to protect the output stage by limiting the maximum current flow through each transistor. If these lamps should glow brightly over a period of time, it could be an indication of trouble, probably in the amplifier output circuit.

Another method of troubleshooting is to narrow the problem down to a particular functional group. This method is not recommended under

normal troubleshooting techniques since it involves pulling patchcords and replacing them with another source of voltage. The process of pulling analog patchcords should be avoided if possible since there is always the probability of misplacing the lead when repatching. If this method is used, however, all that need be done is that all input patch connections to the functional group in question should be removed and replaced with inputs which come from spare hand set potentiometers and spare amplifiers. These input voltages can then be adjusted to the voltage that would have entered that point at the full power level or full full condition. The computer can then be put in the compute condition and voltages of all amplifiers checked.

4.1.3 Cooldown Simulation Troubleshooting

4.1.3.1 General

The cooldown eleven basic lumps are made up of fluid compliances, inertances and resistances. Each lump is controlled by the logic chassis and control signals from the Process System. A careful study of each lump will disclose that each lump can be divorced from the overall subsystem, thereby providing a means of isolating the individual problem.

The two patchboards, logic and analog, will be the method of divorcing the computation lumps.

The LN₂ line will be discussed in detail to illustrate the means of isolating the individual lumps.

4.1.3.2 Local Control (IC and Compute)

The line goes into compute by virtue of the line valves position which is interfaced into the logic chassis and controls one IC and compute bus. It will be necessary to bypass the valve command logic and

enable the local IC and compute located on the logic patchboard. This patching is shown on Table 10. After the logic board has been patched for local control, each half racks mode switch now controls the compute, reset and hold modes for that half rack.

TABLE 10

LN₂ LOCAL MODE CONTROL

I. C. Bus			Compute Bus	
From	To	Rack	From	To
G30	H30	61B	G32	H32
J30	K30	60A	J32	K32
L30	M30	59A	L32	M32
N30	P30	59B	N32	P32
Q30	R30	58A	Q32	R32
S30	T30	58B	S32	T32

Additional patching is required to bypass the logic switch which normally controls the IC and compute relays for each 1/2 rack. This patching is shown on Table 11.

TABLE 11

LN₂ IC AND COMPUTE RELAY BYPASS

I. C.			Compute	
From	To	Rack	From	To
A22	A23	61B	G22	G23
B22	B23	59B	H22	H23
C22	C23	58A	J22	J23

4.1.3.3 Sharing Relays

Each computation lump with the exception of GHe source group and PCV actuators are sharing amplifiers. LN_2 and LH_2 the sharing relay is K11. The sharing takes place in the liquid control, liquid feed, and common manifold functional groups.

The share relays K11 can be controlled locally by proving Logic Hi as shown in Table 12.

TABLE 12

LOCAL CONTROL OF K11 RELAY

From	To
M23	Logic Hi
P23	Logic Hi
Q23	Logic Hi

4.1.3.4 Valve Commands

The valve commands originate at the Process System Consoles, therefore the interface between the process system and simulator must be broken and a simulated (artificial) voltage can be introduced at the analog patch board to operate the simulated valves. All valve commands are +28VDC with the exception of the PCV which are -3 v to open and +3 v to close. Table 13 shows where the artificial voltage is amplified to operate the valves.

TABLE 13

LN₂ RSV & PCV VALVE BYPASS

From	To	Valve
Artificial Voltage	41HH	PCV 517
Artificial Voltage	45T	RSV 545
Artificial Voltage	45R	CDSV

4.1.3.5 LN₂ Lump Isolation

4.1.3.5.1 General

The LN₂ line consists of three lumps (1) Control Group, (2) Feed Group and (3) Common Manifold. Each lump will be discussed in detail so that individual problems can be isolated. Also if each lump will play by itself it is assumed that the whole line will play in its entirety with the logic chassis.

4.1.3.5.2 LN₂ Control Group

The LN₂ control group consists of the following key signals P_1 , $\dot{W}_1$, P_2 , $\dot{W}_2$ and PCV 517 demand (refer to AGC Drawing 1114289 sheet 3). The method used to verify this group's performance is to decouple all signals being fed from the LN₂ feed group. So the LN₂ control group appears to be a one lump simulation.

The following steps will accomplish the above:

(1) Unpatch on the analog board Z20 to HH38. This disables P_3 , downstream pressure, from the feed group.

(2) Unpatch on the analog board U16 and T17 to HH37.

(3) Patch on the analog board HH37 to V41. This bypasses 01L racks simulate/operate mode control.

(4) Unpatch on the analog board T16 to HH41.

(5) Patch on the analog board a variable pot wiper to HH41, analog board, and the high side of the pot to +10 v. This bypasses the demand signal to PCV 517, generated in the process system, and introduces a variable demand voltage determined by the pot wiper.

(6) Remove the following patches on the logic board.

(a) N23 through Z23.

(b) N20 through Z20.

This disables the logic interaction between LH_2 and LN_2 lines.

(7) Patch on logic board N23, P23 and Q23 to logic HI, H4, H5, J4, J5, K4 and K5.

This energizes the K11 relay.

(8) Remove the patching on logic board from A22 to A21, B22 to B21, C22 to C21, G22 to G21, H22 to H21 and J22 to J21.

(9) Patch on the logic board A22 to A23, B22 to B23, C22 to C23, G22 to G23, H22 to H23 and J22 to J23.

This enables the local mode control to the integrator.

(10) Patch the IC and compute buses.

(11) Reset Rack 61B with its local mode control switch.

(12) Table 14 shows the voltage readings of the various amplifiers within the LN₂ control group in reset mode and compute mode.

In the compute mode monitor the output voltage of A 6172 and adjust the lift demand pot (Step 5) for an output of +4.85 v.

TABLE 14
VOLTAGE READING FOR LN₂ CONTROL GROUP IN
RESET AND COMPUTE MODES

Amplifier Number	Function	Voltage	
		Reset Mode	Compute Mode
6177	$\dot{\underline{w}}_1$	0	0
6178	$-\dot{\underline{w}}_1$	0	-10
6179	$\underline{P}_2/2$	5	+4.61
6180	$\dot{\underline{w}}^2$	0	+10
6155	$-(\underline{P}_2 - \underline{P}_3)$	-10	-9.22
6173	$(\underline{P}_2 - \underline{P}_3)^{1/2}$	+10	+9.6
6174	$-(\underline{P}_2 - \underline{P}_3)^{1/2}$	-10	-9.6
6172	$\underline{Ae} \text{ pcv}$	0	+4.85
6175	$-\underline{Ae} \text{ pcv}$	0	-4.85
6170	$\underline{Ae} \text{ pcv } (\underline{P}_2 - \underline{P}_3)^{1/2}$	0	+4.65
6182	$\frac{\dot{\underline{w}}_2}{2}$	0	+5

4.1.3.5.3 LN₂ Feed Group

The LN₂ feed group consists of the following key signals $\dot{\underline{w}}_2$, $\underline{P}_3$, $\dot{\underline{w}}_3$, $\underline{P}_{13}$ and RSV 545 demand (refer to AGC Drawing 114289 sheet 4).

The method used to verify this group's performance is to decouple all signals being fed from the LN₂ control group and common manifold group, so that the LN₂ feed group appears to be a one lump simulation. The following steps will accomplish the above.

- (1) Reset racks 59A and 59B.
- (2) Unpatch on the analog board Y37 to HH20.
- (3) Patch on the analog board +5 v from a low impedance source into HH20. This voltage simulates full weight flow of 100 lb/sec of flow into the lump.
- (4) Unpatch on the analog board Y7 to FF20. This disables the downstream pressure P₁₃.
- (5) Unpatch on the analog board U45 to T45. This removes RSV 545 demand signal from the process system.
- (6) Patch on the analog board +28 v DC through a function switch to T45 on the analog board. This simulates the demand signal to RSV 545.
- (7) Table 15 shows the voltage readings of the various amplifiers within the LN₂ feed group in the reset and compute modes. To obtain voltage readings in the compute mode it is necessary to operate the RSV 545 with the function switch.

TABLE 15

VOLTAGE READINGS FOR LN₂ FEED GROUP IN
RESET AND COMPUTE MODES

Amplifier Number	Function	Voltage	
		Reset Mode	Compute Mode
5974	$-\underline{P}_3/2$	0	-.295
5933	$10\Delta P$	0	.864
5977	$-\sqrt{10\Delta P}$	± 0.5	-2.94
5976	$\sqrt{10\Delta P}$	± 0.5	+2.94
5979	$\underline{Ae} \ 545 \ \sqrt{10\Delta P}$	0	+2.95
5964	$-\dot{\underline{w}}_3$	0	-10.0
5978	$\dot{\underline{w}}_3^2$	0	+10.0

4.1.3.5.4 Liquid Common Manifold

The LN₂ common manifold consists of the following key signals P_{13} , P_{16} , $\dot{w}_{13}$, $\dot{w}_{16}$ and CDV demand (refer to AGC Drawing 1114289 sheets 5 and 6). The method used to verify this group's performance is to decouple all signals being fed from the LN₂ feed group and the engine. So that the LN₂ common manifold group appears to be a one lump simulation, the following steps will accomplish the above:

- (1) Reset Rack 58A.
- (2) Unpatch on the analog board S45 to R45.
- (3) Patch on the analog board +28 v through a function switch and patch on the analog board to R45. This simulates the demand from the CDSV.
- (4) Unpatch on the analog N23 from HH6 and patch the N23 end to ground.

(5) Unpatch W20 to FF6. This divorces the liquid feed group from the common manifold.

(6) Patch on the analog board FF6 to -10 v. This simulates full flow into the common manifold group.

(7) Table 16 shows the voltage readings of the various amplifiers within the LN₂ common manifold group in the reset and compute modes. To obtain the voltages readings in the compute mode it will be necessary to operate the CDRV with the function switch.

TABLE 16

VOLTAGE READINGS FOR LN₂ COMMON MANIFOLD
GROUP IN THE RESET AND COMPUTE MODES

<u>Amplifier Number</u>	<u>Function</u>	<u>Voltage</u>	
		<u>Reset Mode</u>	<u>Compute Mode</u>
5819	$\underline{P}_{13}$	0	+3.76
5835	$\underline{P}_{16}$	0	-0.493
5809	$-\dot{\underline{w}}_{16}$	0	-10
5803	$+\dot{\underline{w}}_{16}$	0	+10
5806	$-\dot{\underline{w}}_{16}^2$	0	+10
5836	$-\dot{\underline{w}}_{13}$	0	-10
5837	$\dot{\underline{w}}_{13}$	0	+10
5829	10ΔP	0	+1.23
5805	$\sqrt{10\Delta P}$	±.5	+1.11

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- NOTES: 1. INTERPRET DWG PER STANDARDS PRESCRIBED IN MIL-D-70327
 2. REMOVED.
 3. RELAY SELECT MODES TO OPERATE AS FOLLOWS:
 A. K1-
 a) DE-ENERGIZED SIMULATES LH₂, LN₂, & GH₂
 b) ENERGIZED SIMULATES GH₂
 B. K2-
 a) ENERGIZED IN COOL DOWN SIMULATE CONDITIONS.
 4. THE FOLLOWING SYMBOLS DENOTE:
 (L) = LOGIC PATCH PANEL POINTS
 (A) = ANALOG " " "
 (M) = MODULOK TERMINATIONS
 (O) = OVERLOAD INDICATOR LIGHT
 5. THIS DWG USED IN CONJUNCTION WITH SCHEMATIC DIAGRAM, LINEAR POWER RANGE GENERATOR - 1114548.
 6. AMPLIFIERS ARE ROLLED OFF WITH A 1,000 PICO FARAD CAPACITOR UNLESS OTHERWISE NOTED AND THE FOLLOWING AMPLIFIERS HAVE NO ROLL OFF CAPACITORS: 6108, 6109, 6216, 6217, 6218, 6219, 6262, 6263, 6284, 6285, 6286 & 6287.

REVISIONS			
ZONE	LTR	DESCRIPTION	DATE
E		SEE DCN. EFFECTS SH1 THRU 15. WAS 2 SHEET DWG	8/23/66
F		SEE DCN. AFFECTS SH 2 THRU 14	10/17/66
G		SEE DCN AFFECTS SH 1, 8, 10, 12, 13 & 14	2-20-67
H		SEE DCN AFFECTS SH 2, 3, 5, 7, 8, 9 & 13	3-17-67
J		SEE DCN AFFECTS SH 2, 3, 4, 5, 7, 8, 9, 10, 12 & 13	5/24/67
K		SEE K DCN	11-7-67
L		SEE L DCN	5-28-68
M		SEE M DCN	8/17/68

QTY REQD	SYM	CODE IDENT	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	UNIT WT	ZONE	ITEM NO
LIST OF MATERIALS									
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DECIMAL TOL XX ± .03 ANGULAR TOL XXX ± .010 DO NOT SCALE DRAWING					CONTRACT NO. DRAWN SCHNEIDER 8-17-66 CHECKED B HANNAH 12-21-65 DESIGN BASILIUS 12-15-65 STRESS NEVENZEL 12-15-65 MATLS/PROCESS C. MARRALL 12-15-65 FAB/MFG ENGR D.E. CARPENTER 12-15-65 PRODUCT ASSURANCE W.A. CHAPLA 12-15-65 DESIGN ACTIVITY APPD V. H. CHANG 12-15-65 R.H. DANIELSON 12-15-65				
TREATMENT FINISH SIMILAR TO					AEROJET-GENERAL CORPORATION SACRAMENTO, CALIFORNIA ROCKET ENGINE OPERATIONS - NUCLEAR TITLE COMPUTER DIAGRAM, ENGINE SIMULATION- ETS-1, TSCS				
PART DASH NO ACT CALC ON THRU WEIGHT EFFECTIVE SERIAL NO USAGE DATA WTS APPD					DWG CODE IDENT NO SIZE C 05824 DWG NO 1114313 SCALE NONE RELEASE DATE 12-22-65 SHEET 10 of 15				

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NOTES:

QTY REQD	SYM	CODE IDENT	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	UNIT WT	ZONE	ITEM NO.
LIST OF MATERIALS									
CONTRACT NO.					AEROJET-GENERAL CORPORATION SACRAMENTO, CALIFORNIA ROCKET ENGINE OPERATIONS - NUCLEAR				
DRAWN SCHNEIDER					DATE				
CHECKED					TITLE				
DESIGN					COMPUTER DIAGRAM, ENGINE SIMULATION - ETS-1, TSCS				
STRESS					DWG NO				
MAT'L/PROCESSES					C 05824 1114313				
FAB/MFG ENGR					SCALE NONE				
PRODUCT ASSURANCE					RELEASE DATE 12-22-65				
DESIGN ACTIVITY APPD					SHEET 2

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NOTES:

QTY REQD		SYM	CODE IDENT	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	UNIT WT	ZONE	ITEM NO
LIST OF MATERIALS										
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DECIMAL TOL XX ± .03 ANGULAR TOL XXX ± .010 DO NOT SCALE DRAWING						CONTRACT NO. DRAWN SCHNEIDER DATE				
TREATMENT						DESIGN STRESS MATERIALS/PROCESSING FAB/MFG ENGR PRODUCT ASSURANCE DESIGN ACTIVITY APPD				
FINISH						SIMILAR TO				
REON						AEROJET-GENERAL CORPORATION SACRAMENTO, CALIFORNIA ROCKET ENGINE OPERATIONS - NUCLEAR				
TITLE COMPUTER DIAGRAM, ENGINE SIMULATION - ETS-1, TSCS						DWG NO 05824 1114313				
SCALE NONE						RELEASE DATE 12-22-65 SHEET 3				

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NOTES:

SIMULATED EQUATIONS
 1. $T_0 = T_0 + (0.0222) T_0$
 2. $T_0 = (0.999) T_0 + (14.44) [\theta_{R_0} - (0.5) (T_0 + T_0)]$
 3. $[\theta_{R_0} / 100] = f([H_0 / 2500])$
 4. $H_0 = T_{0_{\text{sat}}} + 10,000$
 5. $H_0 = (150) T_0 - (15) W_0 - (10.5) T_0 + T_0$ for LH_1, LH_2, GH_2
 6. $H_0 = (190) T_0 - (15.5) W_0 - (10.5) T_0 + T_0$ for GH_1

REFLECTOR FUNCTIONAL GROUP

QTY REQD	SYM	CODE IDENT	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	UNIT WT	ZONE	ITEM NO.
LIST OF MATERIALS									
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DECIMAL TOL .03 ANGULAR TOL .010 DO NOT SCALE DRAWING					CONTRACT NO. DRAWN SCHNEIDER DATE				
TREATMENT					CHECKED				
FINISH					DESIGN				
SIMILAR TO					STRESS				
					MATLS/PROCESSES				
					FAB/MFG ENGR				
					PRODUCT ASSURANCE				
					DESIGN ACTIVITY APPD				
					TITLE COMPUTER DIAGRAM, ENGINE SIMULATION ETS-1, TSCS				
					DWG NO. 05824				
					DWG NO. 1114313				
					SCALE NONE				
					RELEASE DATE 12-22-65				
					SHEET 4				

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NOTES:

REACTIVITY FUNCTIONAL GROUP

QTY REQD	SYM	CODE IDENT	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	UNIT WT	ZONE	ITEM NO.
LIST OF MATERIALS									
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DECIMAL TOL XX ± .03 XXX ± .010 DO NOT SCALE DRAWING					CONTRACT NO. DRAWN SCHNEIDER DATE CHECKED DESIGN STRESS MATLS/PROCESSES FAB/MFG ENGR PRODUCT ASSURANCE DESIGN ACTIVITY APPD				
TREATMENT FINISH SIMILAR TO					AEROJET-GENERAL CORPORATION SACRAMENTO, CALIFORNIA ROCKET ENGINE OPERATIONS - NUCLEAR TITLE COMPUTER DIAGRAM, ENGINE SIMULATION-- ETS-1, TSCS DWG SIZE C CODE IDENT NO. 05824 DWG NO. 1114313 SCALE NONE RELEASE DATE 12-22-65 SHEET 5				

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NOTES:

SIMULATED EQUATION:

$$\begin{aligned} [T_{13}/200] &= \frac{(2.66) [T_6/500] + (0.085) [10X_m] [T_6/60]}{(0.1) [10X_m] + 2.86} \\ &= \frac{(5.32 \times 10^{-3}) T_6 + (1.47 \times 10^{-2}) X_m T_6}{X_m + 2.86} \end{aligned}$$

DILUENT VALVE FUNCTIONAL GROUP
CIRCUITRY WIRED IN BUT NOT USED IN
COMPUTER SOLUTION

QTY REQD	SYM	CODE IDENT	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	UNIT WT	ZONE	ITEM NO.
LIST OF MATERIALS									
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DECIMAL TOL XX ± .03 XXX ± .010 DO NOT SCALE DRAWING					CONTRACT NO. DATE				
TREATMENT					DRAWN SCHNEIDER				
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SIMILAR TO					STRESS				
					MATLS/PROCESSES				
					FAB/MFG ENGR				
					PRODUCT ASSURANCE				
					DESIGN ACTIVITY APPD				
					TITLE				
					COMPUTER DIAGRAM, ENGINE SIMULATION - ETS-1, TSCS				
					DWG SIZE				
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					SCALE				
					NONE				
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NUCLEAR INSTRUMENTATION FUNCTIONAL GROUP

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QTY REQD		SYM	CODE IDENT	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	UNIT WT	ZONE	ITEM NO.
LIST OF MATERIALS										
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES					CONTRACT NO.		AEROJET-GENERAL CORPORATION SACRAMENTO, CALIFORNIA ROCKET ENGINE OPERATIONS - NUCLEAR			
DECIMAL TOL XX ± .03 XXX ± .010		ANGULAR TOL - 2°			DRAWN <u>SCHNEIDER</u>		DATE		TITLE	
DO NOT SCALE DRAWING					CHECKED				COMPUTER DIAGRAM, ENGINE SIMULATION- ETS-1, TSCS	
TREATMENT					DESIGN					
					STRESS					
					MAT'LS/PROCESSES					
					FAB/MFG ENGR		DWG SIZE		CODE IDENT NO	DWG NO
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QTY REQD	SYM	CODE IDENT	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	UNIT WT	ZONE	ITEM NO
LIST OF MATERIALS									
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DECIMAL TOL XXX - 03 XXX - 010 DO NOT SCALE DRAWING					CONTRACT NO DRAWN SCHNEIDER CHECKED DESIGN STRESS MATERIALS/PROCESSES FAB/MFG ENGR PRODUCT ASSURANCE DESIGN ACTIVITY APPD				
TREATMENT					FINISH				
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SEE SHEET 10

FLOW FUNCTIONAL GROUP

QTY REQD	SYM	CODE IDENT	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	UNIT WT	ZONE	ITEM NO.
LIST OF MATERIALS									
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DECIMAL TOL .010 ANGULAR TOL + 2° DO NOT SCALE DRAWING					CONTRACT NO. 1114313 DRAWN SCHNEIDER CHECKED DESIGN STRESS MATLS/PROCESSES FAB/MFG ENGR PRODUCT ASSURANCE DESIGN ACTIVITY APPD				
TREATMENT FINISH SIMILAR TO					AERJET GENERAL CORPORATION SACRAMENTO, CALIFORNIA ROCKET ENGINE OPERATIONS - NUCLEAR TITLE COMPUTER DIAGRAM, ENGINE SIMULATION- ETS-1, TSCS DWG NO. 1114313 CODE IDENT NO. 05824 SCALE NONE RELEASE DATE 12-22-65 SHEET 9				

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NOTES:

SEE SHEET 9

QTY REQD	SYM	CODE IDENT	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	UNIT WT	ZONE	ITEM NO
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UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DECIMAL TOL XX ± .03 ANGULAR TOL XXX ± .010 DO NOT SCALE DRAWING		CONTRACT NO. DRAWN SCHNEIDER DATE		 AERJET-GENERAL CORPORATION SACRAMENTO, CALIFORNIA ROCKET ENGINE OPERATIONS - NUCLEAR
TREATMENT		TITLE COMPUTER DIAGRAM, ENGINE SIMULATION- ETS-1, TSCS		
FINISH		DWG NO 05824		
SIMILAR TO		DWG NO 1114313		
		SCALE NONE		
DRAWING LEVEL 1		RELEASE DATE 12-22-65		SHEET 10

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NOTES:

SIMULATED EQUATIONS:

- $[\Phi_{c1}/500] = f([L - H_c/6 \times 10^5])$
- $T_0 = 1.7059 \Phi_{c1} - 0.7059 T_6$

- $H_c = (1.08 \times 10^4) \gamma_c - (44.04) W_c [\Phi_{c1} - (0.5)(T_6 + T_0)]$, for LH_2, LN_2, GH_2
- $H_c = (1.08 \times 10^4) \gamma_c - (2.46) W_c [\Phi_{c1} - (0.5)(T_6 + T_0)]$, for GHe
- $H_c = \int^T H_c dt + 180,000$
- $T_{cr} = -\phi_{SG} K_1 + W_c K_2$

CORE FUNCTIONAL GROUP

QTY REQD	SYM	CODE IDENT	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	UNIT WT	ZONE	ITEM NO.
LIST OF MATERIALS									
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DECIMAL TOL XX ± .03 XXX ± .010 DO NOT SCALE DRAWING					CONTRACT NO.				
TREATMENT					DRAWN SCHNEIDER DATE				
FINISH					CHECKED				
SIMILAR TO					DESIGN				
					STRESS				
					MATERIALS/PROCESSES				
					FAB/MFG ENGR				
					PRODUCT ASSURANCE				
					DESIGN ACTIVITY APPD				
					AEROJET-GENERAL CORPORATION SACRAMENTO, CALIFORNIA ROCKET ENGINE OPERATIONS - NUCLEAR				
					TITLE COMPUTER DIAGRAM, ENGINE SIMULATION- ETS-1, TSCS				
					DWG NO C 05824 1114313				
					SCALE NONE RELEASE DATE 12-22-65 SHEET 12				

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NOTES:

SEE SHEET 12

QTY REQD	SYM	CODE IDENT	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	UNIT WT	ZONE	ITEM NO
LIST OF MATERIALS									
<p>UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DECIMAL TOL XX ± .03 ANGULAR TOL ± 2° XXX ± .010 DO NOT SCALE DRAWING</p>									
<p>TREATMENT</p>									
<p>FINISH</p>									
<p>SIMILAR TO</p>									
<p>CONTRACT NO.</p>									
<p>DRAWN SCHWEIDER DATE</p>									
<p>CHECKED</p>									
<p>DESIGN</p>									
<p>STRESS</p>									
<p>MATLS/PROCESSES</p>									
<p>FAB/MFG ENGR</p>									
<p>PRODUCT ASSURANCE</p>									
<p>DESIGN ACTIVITY APPD</p>									
<p>AEROJET-GENERAL CORPORATION SACRAMENTO, CALIFORNIA ROCKET ENGINE OPERATIONS - NUCLEAR</p>									
<p>TITLE COMPUTER DIAGRAM, ENGINE SIMULATION- ETS-1, TSCS</p>									
<p>DWG SIZE C CODE IDENT NO. 05824 DWG NO. 1114313</p>									
<p>SCALE NONE RELEASE DATE 12-22-65 SHEET 13</p>									

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REVISIONS			
SYM	ZONE	DESCRIPTION	DATE
			APPROVED

NOTES:

COMPONENT	FUNCTION	COMPONENT	FUNCTION	COMPONENT	FUNCTION	COMPONENT	FUNCTION	COMPONENT	FUNCTION	COMPONENT	FUNCTION
	HIGH GAIN AMPLIFIER $E = 100 \times E_1 = 100 \times E_2$		INVERTER $V = -X$		SUMMER $V = X + Y + Z$		THE NUMBER OF INPUTS AVAILABLE FOR AMPLIFICATION IS DETERMINED BY THE NUMBER OF INPUTS TO THE SUMMER. THE COMPUTER		USED FOR ISOLATING EXTRA INPUT RESISTORS OF SPECIAL INPUTS MADE DIRECTLY TO SUMMER (SUMMER INPUTS) OF AMPLIFIER		BORROWED INPUT RESISTOR NETWORK
	INTEGRATOR $V = \int X dt$										

COMPONENT	FUNCTION	COMPONENT	FUNCTION	COMPONENT	FUNCTION	COMPONENT	FUNCTION	COMPONENT	FUNCTION	COMPONENT	FUNCTION
	POTENTIOMETER (GROUNDED) $V = KX$ $0 \leq K \leq 1$		POTENTIOMETER (UNGROUNDING) $V = K(X - Y)$ $0 \leq K \leq 1$		SERVO-MULTIPLIER (PLUS CONNECTION) $V = K(X - Y)$ $0 \leq K \leq 1$		QUARTER-SQUARE MULTIPLIER (WITH EXTERNALLY PATCHED AMPLIFIER) $V = \frac{XY}{100}$		DIODE FUNCTION GENERATOR (WITH AMPLIFIERS INCLUDED) $V = \frac{XY}{100}$		DIODE FUNCTION GENERATOR (WITH EXTERNALLY PATCHED AMPLIFIERS) $V = \frac{XY}{100}$

COMPONENT	FUNCTION	COMPONENT	FUNCTION	COMPONENT	FUNCTION	COMPONENT	FUNCTION	COMPONENT	FUNCTION	COMPONENT	FUNCTION
	FEEDBACK LIMITER (SOFT LIMITER) NUMBER OF LIMITS $V = \frac{X}{1 + X^2}$		SOLID STATE DIODE WHEN POINT A IS POSITIVE WITH RESPECT TO X, CURRENT FLOWS FROM A TO X. WHEN POINT A IS NEGATIVE WITH RESPECT TO X, NO CURRENT FLOWS. IT IS NOT NECESSARY TO INCLUDE THE DIODES IN THE CIRCUIT.		TIE POINT TIEPOINT NUMBER ALLOWS MULTIPLE CONNECTIONS TO A SINGLE TERMINAL		MANUAL SWITCH (FUNCTION SWITCH) SWITCH MANUALLY POSITIONED BY OPERATOR. L, C AND R REFER TO LEFT CENTER AND RIGHT. PLUS FORCE OF SWITCH ON CONTROL PANEL.		RELAY COMPARATOR RELAY ARMS MADE TO CONTACTS WHEN $X > Y$ OR $X < Y$ OR $X = Y$. CONTACTS WHEN $X > Y$ OR $X < Y$ OR $X = Y$. COMPARE CONTACTS USED WITH AN EXTERNAL ADJACENT TO THE CONTROL INPUTS X AND Y.		DIVISION CIRCUIT USING QUARTER SQUARE MULTIPLIER (WITH EXTERNALLY PATCHED AMPLIFIER) $V = \frac{X}{Y}$

COMPONENT	FUNCTION	COMPONENT	FUNCTION	COMPONENT	FUNCTION
	SQUARE ROOT CIRCUIT USING FIXED DIODE FUNCTION GENERATOR & HIGH GAIN AMPLIFIER WHERE INPUT X IS (1/2) SQUARE ROOT IS USED IN FEEDBACK TO GIVE SQUARE ROOT OUTPUT $V = \sqrt{X}$		SQUARE ROOT CIRCUIT USING FIXED DIODE FUNCTION GENERATOR & HIGH GAIN AMPLIFIER SAME AS ABOVE		SQUARE ROOT CIRCUIT USING FIXED DIODE FUNCTION GENERATOR & HIGH GAIN AMPLIFIER SAME AS ABOVE

COMPONENT	FUNCTION	COMPONENT	FUNCTION	COMPONENT	FUNCTION
	SQUARE ROOT CIRCUIT USING FIXED DIODE FUNCTION GENERATOR & HIGH GAIN AMPLIFIER SAME AS ABOVE		SQUARE ROOT CIRCUIT USING FIXED DIODE FUNCTION GENERATOR & HIGH GAIN AMPLIFIER SAME AS ABOVE		SQUARE ROOT CIRCUIT USING FIXED DIODE FUNCTION GENERATOR & HIGH GAIN AMPLIFIER SAME AS ABOVE

QTY REQD	SYM	CODE IDENT	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	UNIT WT	ZONE	ITEM NO.
LIST OF MATERIALS									
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DECIMAL TOL XX ± .03 XXX ± .010 DO NOT SCALE DRAWING					DRAWN <u>SCHNEIDER</u> DATE _____ CHECKED _____ DESIGN _____ PROJECT _____ STRESS _____ MATERIALS/PROCESSES _____ FAB/MFG ENGR _____ PRODUCT ASSURANCE _____ DESIGN ACTIVITY APPD _____				
TREATMENT _____					TITLE COMPUTER DIAGRAM, ENGINE SIMULATION- ETS-1, TSCS				
FINISH _____					CODE IDENT NO. <u>05824</u> DWG NO. <u>1114313</u>				
SIMILAR TO _____					SCALE <u>NONE</u> RELEASE DATE <u>12-22-65</u> SHEET <u>15</u>				

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1

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NOTES:
 1. INTERPRET DWG PER STANDARDS PRESCRIBED IN MIL-D-70327.
 2. REFER TO AGC DWG. 1114329 FOR COOLDOWN INFORMATION.

LEGEND CHART	
SYMBOL	DESCRIPTION
T_2, P_2	TEMP & PRESS, PUMP ENTRANCE
T_3, P_3	PUMP DISCHARGE
T_4, P_4	NOZZLE COOLANT TUBE
T_5, P_5	REFLECTOR COOLANT TUBE
T_6, P_6	SHIELD COOLANT TUBE
T_7, P_7	CORE COOLANT TUBE
T_8, P_8	CORE EXIT
T_{10}, P_{10}	TURBINE PWR CONTROL VALVE
T_{15}, P_{15}	TURBINE ENTRANCE
T_{16}, P_{16}	TEMP & PRESS TURBINE EXHAUST
T_{13}	TEMP DILUENT
W_p	FLOW RATE, PROPELLANT
W_r	FLOW RATE, REFLECTOR
W_d	FLOW RATE, DILUENT

REVISIONS		DATE	APPROVED
1	SEE 'A' CHG DCN	9 4 65	
2	SEE DCN	11 16 65	

QTY REQD		SYM	CODE IDENT	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	UNIT WT	ZONE	ITEM NO																				
<div style="display: flex; justify-content: space-between;"> <div> <p>REON</p> <table border="1"> <tr> <th>PART DASH NO</th> <th>ACT</th> <th>CALC</th> <th>ON</th> <th>THRU</th> <th>PART DASH NO</th> <th>NEXT</th> <th>FINAL</th> <th>NEXT ASSY</th> <th>USED ON</th> </tr> <tr> <td>WTS APPD</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> </tr> </table> </div> <div> <p>1114329</p> <p>1114315</p> </div> </div>											PART DASH NO	ACT	CALC	ON	THRU	PART DASH NO	NEXT	FINAL	NEXT ASSY	USED ON	WTS APPD									
PART DASH NO	ACT	CALC	ON	THRU	PART DASH NO	NEXT	FINAL	NEXT ASSY	USED ON																					
WTS APPD																														
<p>UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES</p> <p>DECIMAL TOL .005</p> <p>ANGULAR TOL .010</p> <p>XXX ± .010</p> <p>DO NOT SCALE DRAWING</p>						<p>LIST OF MATERIALS</p> <table border="1"> <tr> <th>DRAWN</th> <th>CHECKED</th> <th>DESIGNED</th> <th>PROJECT</th> <th>STRESS</th> <th>MATERIALS</th> <th>FABRICATION</th> <th>PRODUCT ASSURANCE</th> <th>DESIGN ACTIVITY</th> </tr> <tr> <td>POWELL</td> <td>POWELL</td> <td>POWELL</td> <td>POWELL</td> <td>POWELL</td> <td>POWELL</td> <td>POWELL</td> <td>POWELL</td> <td>POWELL</td> </tr> </table>					DRAWN	CHECKED	DESIGNED	PROJECT	STRESS	MATERIALS	FABRICATION	PRODUCT ASSURANCE	DESIGN ACTIVITY	POWELL	POWELL	POWELL	POWELL	POWELL	POWELL	POWELL	POWELL	POWELL		
DRAWN	CHECKED	DESIGNED	PROJECT	STRESS	MATERIALS	FABRICATION	PRODUCT ASSURANCE	DESIGN ACTIVITY																						
POWELL	POWELL	POWELL	POWELL	POWELL	POWELL	POWELL	POWELL	POWELL																						
<p>AERJET GENERAL CORPORATION SACRAMENTO, CALIFORNIA ROCKET ENGINE OPERATIONS - NUCLEAR</p>						<p>TITLE LH2 ENGINE FLOW DIAGRAM, TSS-1 ETS-1 TSCS CONCEPT</p>																								
<p>CODE IDENT NO 05824</p> <p>SCALE 1/16" = 1"</p>						<p>DWG NO 1114315</p> <p>RELEASE DATE 5-26-65</p> <p>SHEET</p>																								

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GH₂ CONTROL GROUP:-

- $\hat{P}_1 = 100$
- $\hat{I}_3 = 100$
- $\hat{W}_1 = \frac{0.474 \hat{P}_{1201} \hat{P}_1 \hat{N}_{5201}}{\sqrt{\hat{I}_3}}$
- $\hat{P}_1 \hat{N}_{5201} = 2 \hat{P}_{14} (\hat{P}_1 - \hat{P}_8)$ WHEN $\hat{P}_1 \leq 2 \hat{P}_8$
- $\hat{P}_1 \hat{N}_{5201} = \hat{P}_1 \text{ WHEN } \hat{P}_1 \geq 2 \hat{P}_8$
- $\hat{E}_8 = 0.518 \quad \hat{I}_3 (\hat{W}_1 - \hat{W}_8)$
- $\hat{W}_8 = \int_0^t \hat{E}_{8out} dt$; c. WHILE $\hat{P}_8$ IS $\hat{P}_7$ OR $\hat{P}_{14}$
- $\hat{W}_8 = 1.465 \hat{E}_{8in} (\hat{E}_8 - 0.1812 \hat{W}_8)^t \hat{N}_{5251}$ WHERE $C \leq \hat{W}_8$
- $(\hat{P}_8 - 0.1812 \hat{W}_8) \hat{N}_{5251} = 2 \hat{P}_{14} [(\hat{P}_8 - 0.1812 \hat{W}_8)^t - 1]$

SWPD
SIZE
E	CODE IDENT NO.
05824	SWPD NO.
1114289
SCALE
NONE	RELEASE DATE
12-24-65	SHEET
7

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NOTES:
SEE SHEET 1

COMPONENT	FUNCTION	COMPONENT	FUNCTION	COMPONENT	FUNCTION	COMPONENT	FUNCTION	COMPONENT	FUNCTION	COMPONENT	FUNCTION
CIRCLE IN SYMBOL IS OVERLOAD INDICATOR											
NUMBERS 1, 10, etc. ARE USED TO INDICATE THE STANDARD RESISTOR VALUES. P IS DEPENDENT ON THE MACHINE. EXTERNAL FEEDBACK MUST BE USED. THE OUTPUT V IS DETERMINED IMPLICITLY BY THE RELATION $E_1 + 10E_2 + E_3 = 0$		$V = -X$		$V = (X + 10Y + Z)$		USED FOR INDICATING EXTRA INPUT RESISTORS OR SPECIAL INPUTS MADE DIRECTLY TO SUMMER JUNCTION OF AMPLIFIER		INDICATES AN INPUT RESISTOR NETWORK DISCONNECTED FROM ITS ASSOCIATED AMPLIFIER (IN THIS CASE 1/10) AND USED WITH ANOTHER AMPLIFIER (IN THIS CASE 1/10)		$V = V_{IC}$ $V = \int (X + 10Y + Z) dt$	
HIGH GAIN AMPLIFIER	$E_1 + 10E_2 + E_3 = 0$	INVERTER	SOME INVERTERS HAVE INPUT OTHER THAN ONE (1)	SUMMER	THE NUMBER OF INPUTS AVAILABLE FOR AN AMPLIFIER OR SUMMER IS INDICATED UPON THE COMPUTER	AMPLIFIER WITH SUMMER JUNCTION INPUT	NUMBER OF BORROWED INPUT RESISTOR NETWORK	BORROWED INPUT RESISTOR NETWORK		THE MODE CONTROL INPUT IS A LOGIC SIGNAL. FOR CHANGING THE MODE OF THE INTEGRATOR TO CONVENTIONAL MODE CONTROL, IS USED. THIS INPUT MUST BE SWITCHED	INTEGRATOR

COMPONENT	FUNCTION	COMPONENT	FUNCTION	COMPONENT	FUNCTION	COMPONENT	FUNCTION	COMPONENT	FUNCTION	COMPONENT	FUNCTION
NO CHARACTER IN SYMBOL INDICATES KNOWN ADJUST POTENTIOMETER											
T = SCREEN ADJUST TRIMFOOT POTENTIOMETER (GROUNDING)		POTENTIOMETER (UNGROUNDING)		SERVO-MULTIPLIER (PLUS CONNECTION)		QUARTER-SQUARE MULTIPLIER (WITH EXTERNALLY PATCHED AMPLIFIERS)		DIODE FUNCTION GENERATOR (WITH EXTERNALLY PATCHED AMPLIFIERS)		DIODE FUNCTION GENERATOR (WITH EXTERNALLY PATCHED AMPLIFIERS)	
$V = KX$ $0 \leq K \leq 1$		$V = Y + K(X - Y)$ $0 \leq K \leq 1$		$V = \frac{XY}{10}$		$V = \pm \frac{XY}{10}$		$V = f(X)$		$V = f(X)$	
USE ONLY IF X IS ALWAYS POSITIVE		USE ONLY IF X IS ALWAYS POSITIVE		USE ONLY IF X IS ALWAYS POSITIVE		USE ONLY IF X IS ALWAYS POSITIVE		THE SIGN OF THE OUTPUT IS DETERMINED BY INPUT PATCHING		THE SIGN OF THE OUTPUT IS DETERMINED BY INPUT PATCHING	

COMPONENT	FUNCTION	COMPONENT	FUNCTION	COMPONENT	FUNCTION	COMPONENT	FUNCTION	COMPONENT	FUNCTION	COMPONENT	FUNCTION
NUMBER OF LIMITS LIMITS X Y MAY BE USED WITH ANY TYPE OF AMPLIFIER (SUMMER, INTEGRATOR, ETC.)		WHEN POINT A IS POSITIVE WITH RESPECT TO K, CURRENT FLOWS FROM A TO K. WHEN POINT A IS NEGATIVE WITH RESPECT TO K, NEGLECTABLE CURRENT FLOWS. IT IS NOT NECESSARY TO INCLUDE THE LETTERS A AND K ON THE DIAGRAM		ALLOWS MULTIPLE CONNECTIONS TO A SINGLE TERMINAL		RELAY ARMS MAKE TO + CONTACTS WHEN $X + Y > 0$ AND TO - CONTACTS WHEN $X + Y < 0$. COMPARTMENT CONTACTS NEED NOT BE DRAWN ADJACENT TO THE CONTROL INPUTS X AND Y		$V_o \approx \frac{XY}{10}$ THE SIGN OF THE OUTPUT IS DETERMINED BY INPUT AC CING THE "X" QUANTITY INPUT CAN BE A (1) VALUE ONLY.		
FEEDBACK LIMITER (SOFT LIMITER)		SOLID-STATE DIODE		TIE POINT	MANUAL SWITCH (FUNCTION SWITCH)	RELAY COMPARATOR		DIVISION CIRCUIT USING QUARTER SQUARE MULTIPLIER (WITH EXTERNALLY PATCHED AMPLIFIER)			

COMPONENT	FUNCTION	COMPONENT	FUNCTION	COMPONENT	FUNCTION
SQUARE ROOT CIRCUIT USING FIXED DIODE FUNCTION GENERATOR & HIGH GAIN AMPL.		SQUARE CIRCUIT USING FIXED DIODE FUNCTION GENERATOR & HIGH GAIN AMPLIFIER		CONSOLE DESIGNATION	
WHERE INPUT X IS (+) SQUARE CARD IS USED IN FEEDBACK TO GIVE SQUARE ROOT OUTPUT					
$V = -\sqrt{10}X$		$V = -\frac{X^2}{10}$			
SQUARE ROOT C.K.T. USING FIXED DIODE FUNCTION GENERATOR (WITH INTERNALLY PATCHED AMPLIFIER)		SQUARE C.K.T. USING FIXED DIODE FUNCTION GENERATOR (WITH INTERNALLY PATCHED AMPLIFIER)		PERMITS INTERCONNECTION BETWEEN CONSOLES	
SAME AS ABOVE		SAME AS ABOVE			

COMPONENT	FUNCTION
DIVISION CIRCUIT USING QUARTER SQUARE MULTIPLIER (WITH EXTERNALLY PATCHED AMPLIFIER)	
DIVISION CIRCUIT USING QUARTER SQUARE MULTIPLIER (WITH INTERNALLY PATCHED AMPLIFIERS) DENOMINATOR Y CAN BE SHOWN ENTERING TOP OR BOTTOM	

☐ ADCN		☒ DCN		DATE 4-26-68		DOCUMENT CHANGE NOTICE AEROJET GENERAL CORPORATION SACRAMENTO, CALIFORNIA CODE IDENT. NO. 05824		DWG. LVL 1		DOCUMENT NUMBER 1114289		CHG. LTR. M					
INCORPORATED BY		DATE / /		☒ DRAWING ☐ STANDARD ☐ SPECIFICATION				DOCUMENT TITLE COMPUTER DIAGRAM COOLDOWN SIMULATION ETS-1, TSCS		SHEET 1 OF 1							
CHECKED BY		DATE / /															
REASON FOR CHANGE						PROJ: <i>ETS-1, TSCS</i>		APPROVALS									
FACILITATE FABRICATION		DESIGN CHANGE		DRAFTING ERROR		OTHER ECR-1324-000		DES. ACTIVITY <i>Design</i>		PREPARED BY C.E. DAVIS		STRUCTURE/STRESS		MATERIALS		RELEASE DATE 8-17-68	
CUSTOMER CHANGE		DESIGN ERROR		ADDITION DESIGN INFO.				DESIGN <i>Design</i>		CHECK <i>J. E. Davis</i> 8-5-68		PRODUCTION		PAD		CUSTOMER	

ITEM

1. CHANGES TOO NUMEROUS TO LIST SEE "L" CHANGE DWG FOR "WAS" CONDITION.

NOTES:

1. INTERPRET DWG PER STDS PRESCRIBED IN AIL-D-70327.
2. ONLY THE ITEMS LISTED ON THIS DWG & IDENTIFIED BY VENDORS NAME, ADDRESS AND PART NO. HAVE BEEN TESTED & APPROVED BY AGC REON TSCS C&C ENGINEERING FOR USE. ETS-1, TSS-A SUBSTITUTE ITEM SHALL NOT BE USED WITH JT PRIOR TESTING & APPROVAL BY AGC REON TSCS ENGINEERING.
3. CLEAR PER AGC-STO 9037, LE I.I.
4. PRESERVE & PACKAGE PER AGC-46387, CLASS 1.
5. MARK PER ASD 5215H (WITH VENDOR'S NAME, ADDRESS & PRT NO., & AGC SCD 13). 1114573-9.
6. THESE PARTS ARE SUPPLIED BY AGC 1115260-1, AS 9703A-1-1, AND OF 1025.
7. DESIGN & ACCEPTANCE CRITERIA PER AGC 90073 TO BE IN CONJUNCTION WITH RACK 60 RUNNIN LIST DWG NO 1134288
8. MODULOLOS TB1-152 THRU TB1-176AND TB2-152 THRU TB2-176 REQUIRED FOR INTERFERENCE TERMINATIONS

REVIEWS		
LYR TONE	DESCRIPTION	DATE APPROV
A	SEE DCM AFFECTS SH 1 # 1 3	2/16/67
B	SEE INCORP ADCN	2/28/68
C	SEE DCM, AFFECTS SH 1 2 # 3	2/29/68
D	SEE DCM, AFFECTS SH 1 # 2	2/29/68
E	SEE DCM AFFECTS SH 1 2 # 3	2/29/67
F	SEE DCM AFFECTS SH 2 # 3	2/29/67
G	SEE G DCM	2/29/67

4 REQD

△ 1115260-1

SOURCE CONTROL DRAWING

-9	0000101160A	ELECTRONIC ASSOCIATE 5 INC	81867
AGC DASH NO.	VENDOR PART NO.	VENDOR	CODE IDENT NO.
SOURCE OF SUPPLY			

[illegible][illegible]

SLE SHT 1 FOR GEN NOTES

RACK INTERFACE CHART

T82			
RAC: 60			
MODULOK NUMBER	Y	MODULOK SIDE	INTERFACE SIGNAL X MODULOK SIDE
A	B	C	D
1	X	X	X
2	X	X	X
3	X	X	X
4	X	X	X
5	X	X	X
6	X	X	X
7	X	X	X
8	X	X	X
9	X	X	X
10	X	X	X
11	X	X	X
12	X	X	X
13	X	X	X
14	X	X	X
15	X	X	X
16	X	X	X
17	X	X	X
18	X	X	X
19	X	X	X
20	X	X	X
21	X	X	X
22	X	X	X
23	X	X	X
24	X	X	X
25	X	X	X
26	X	X	X
27	X	X	X
28	X	X	X
29	X	X	X
30	X	X	X
31	X	X	X
32	X	X	X
33	X	X	X
34	X	X	X
35	X	X	X
36	X	X	X
37	X	X	X
38	X	X	X
39	X	X	X
40	X	X	X
41	X	X	X
42	X	X	X
43	X	X	X
44	X	X	X
45	X	X	X
46	X	X	X
47	X	X	X
48	X	X	X
49	X	X	X
50	X	X	X
51	X	X	X
52	X	X	X
53	X	X	X
54	X	X	X
55	X	X	X
56	X	X	X
57	X	X	X
58	X	X	X
59	X	X	X
60	X	X	X
61	X	X	X
62	X	X	X
63	X	X	X
64	X	X	X
65	X	X	X
66	X	X	X
67	X	X	X
68	X	X	X
69	X	X	X
70	X	X	X
71	X	X	X
72	X	X	X
73	X	X	X
74	X	X	X
75	X	X	X
76	X	X	X
77	X	X	X
78	X	X	X
79	X	X	X
80	X	X	X
81	X	X	X
82	X	X	X
83	X	X	X
84	X	X	X
85	X	X	X
86	X	X	X
87	X	X	X
88	X	X	X
89	X	X	X
90	X	X	X
91	X	X	X
92	X	X	X
93	X	X	X
94	X	X	X
95	X	X	X
96	X	X	X
97	X	X	X
98	X	X	X
99	X	X	X
100	X	X	X

RACK INTERFACE CHART

RACK 60				INTERFACE SIGNAL	
MODULOK NUMBER	A	B	Y SIDE	MODULOK	SIDE
61				TURBINE INLET TEMP SIGNAL (T13)	
62	X			TURBINE INLET TEMP SHIELD	
62	X			CHAMBER PRESS SIGNAL	
63				CHAMBER PRESS SHIELD	
63	X		X	STATION 1/2+1 TEMP SIGNAL	
64				STATION 1/2-1 TEMP SHIELD	
64	X		X	STATION 20 TEMP SIGNAL	
75				STATION 20 TEMP SHIELD	
75		X		ANALOG RECORD CHANNEL #1	H1
75	X			ANALOG RECORD CHANNEL #1	H1 SHLD
76		X		ANALOG RECORD CHANNEL #2	H1
76		X		ANALOG RECORD CHANNEL #2	LO
77				ANALOG RECORD CHANNEL #2	SHLD
77		X	X	ANALOG RECORD CHANNEL #3	H1
77	X			ANALOG RECORD CHANNEL #3	LO
78				ANALOG RECORD CHANNEL #3	SHLD
78		X		ANALOG RECORD CHANNEL #4	H1
78	X			ANALOG RECORD CHANNEL #4	LO
79		X		ANALOG RECORD CHANNEL #4	SHLD
79		X	X	ANALOG RECORD CHANNEL #5	H1
79	X			ANALOG RECORD CHANNEL #5	LO
80				ANALOG RECORD CHANNEL #5	SHLD
80	X		X	ANALOG RECORD CHANNEL #6	H1
80		X		ANALOG RECORD CHANNEL #6	LO
81		X	X	ANALOG RECORD CHANNEL #7	H1
81	X			ANALOG RECORD CHANNEL #7	LO
82				ANALOG RECORD CHANNEL #7	SHLD
82		X	X	ANALOG RECORD CHANNEL #8	H1
82	X			ANALOG RECORD CHANNEL #8	LO
83				ANALOG RECORD CHANNEL #8	SHLD
83		X	X	ANALOG RECORD BINARY CH#1	H1
83	X			ANALOG RECORD BINARY CH#1	LO
83	X			ANALOG RECORD BINARY CH#2	LO
84				ANALOG RECORD BINARY CH#2	SHLD
84		X	X	ANALOG RECORD BINARY CH#3	H1
85		X		ANALOG RECORD BINARY CH#3	LO
85	X			ANALOG RECORD BINARY CH#4	H1
86	X			ANALOG RECORD BINARY CH#4	LO
86				ANALOG RECORD BINARY CH#4	SHLD
87			X	SCOPE VERT A/P A	H1
87		X		SCOPE VERT A/P A	LO
87	X			SCOPE VERT A/P A	SHLD
88		X		SCOPE VERT A/P B	H1
88		X		SCOPE VERT A/P B	LO
88	X			SCOPE VERT A/P B	SHLD
89		X	X	SCOPE HORIZ AMP	H1
89	X			SCOPE HORIZ AMP	SHLD
90		X		SCOPE TRIGGER	H1
90	X		X	SCOPE TRIGGER	SHLD
91	X			DVM FREQ MEAS	H1
92		X	X	DVM DC INPUT	H1
92		X		DVM DC INPUT	LO
92	X			DVM DC INPUT	SHLD
93		X	X	FUNCTION ANALYZER	INPUT H1
93	X			FUNCTION ANALYZER	INPUT LO
94				FUNCTION ANALYZER	OUTPUT H1
94	X		X	FUNCTION ANALYZER	OUTPUT LO
94	X			FUNCTION ANALYZER	SHLD
95				ADJ DC	+ COMMON
95	X			ADJ DC	- COMMON
96		X		ADJ DC	SHLD
96	X		X	FUNCT. GEN OUTPUT	B+ H1
97		X		FUNCT. GEN OUTPUT	SHLD
97	X		X	FUNCT. GEN OUTPUT	A- SHLD
98		X		FUNCT. GEN OUTPUT	H1 #1
98	X			RAMP GENERATOR	H1 #2
98		X	X	RAMP GENERATOR	H1 #3
99				RAMP GENERATOR	LO
99	X			RAMP GENERATOR	SHLD
99	X			RAMP GENERATOR	H1
100		X	X	+ 10 VDC	LO
101				+ 10 VDC	SHLD
101	X		X	- 10 VDC	LO
102				- 10 VDC	SHLD
102	X		X	LOG COUNT RATE	LO
62				LOG COUNT RATE RET	SHLD
65	X			LOG COUNT RATE 5-10	
27				TT8B1SIG AL	
27	X			TT8B1SHLD	
28		X	X	PT8B1SIGNAL	
28	X			PT8B1SHLD	
29				SPARE	
29	X				
30		X	X		
30	X				
31		X			
31	X		X		
32					
33		X	X		
33	X			SPARE	
66			X	SPARE FROM RACK 45	
66		X		SPARE FROM RACK 45	
66	X			SPARE FROM RACK 45	
35			X	DVM HI	
35		X		DVM LO	
35	X			DVM	

RAC INTERFACE CHART

RACK 60				TB2
MODULOK NUMBR	Y MODULOK SIDE			INTERFACE SIGNAL X MODULOK SPARE
	A	B	D	
110			X	REFLECTOR TEMP
110	X			REFLECTOR TEMP SHLD
111			X	STATION 32
111	X			STATION 32 SHLD
112			X	
112	X			
113			X	
113	X			
114	X			
115			X	
115	X			
116			X	
116	X			
117	X		X	
118			X	
118	X			
119				
119	X		X	
120			X	
120	X			
121			X	
121	X			
122			X	
122	X			
123			X	
123	X			
124			X	
124	X			
125			X	
125	X			
126			X	
126	X			
127			X	
127	X			
128			X	
128	X			
129			X	
129	X			
130			X	
130	X			
131			X	
131	X			
132			X	
132	X			
133			X	
133	X			
134			X	
134	X			
135	X			PCV251M SHLD JPR TO 60TB2-137-B
135		X		
135			X	
135	X		X	PCV251M JPR TO 60TB2-137-C
136	X	X		PCV472M SHLD JPR TO 60TB2-142-B
136			X	
136			X	PCV472M JPR TO 60TB2-142-C
137	X			TP475 SHIELD
137		X		JPR TO 60TB2-137-A
137			X	PCV 251 METER SIGNAL
137			X	PT 475 SIGNAL
138	X			TT 510 SHIELD
138		X		JPR TO 60TB2-138-A
138			X	PCV471 METER SIGNAL
138			X	TT 510 SIGNAL
139	X			PT 580 SHIELD
139		X		
139			X	SPARE TO RACK 67
139			X	PT 580 SIGNAL
140	X			TT 511 SHIELD
140	X	X		JPR TO 60TB2-140-A
140			X	PT 587 SIGNAL
140			X	TT 511 SIGNAL
141	X			PT 587 SHLD JPR TO 60TB2-140-B
141		X		
141			X	
141			X	PT 587 JPR TO 60TB2-140-C
142	X			PT 3 SHIELD
142		X		JPR TO 60TB2-142-A
142			X	PCV 472 METER SIGNAL
142				PT 3
143	X			PCV471M SHLD JPR TO 60TB2-138-B
143	X		X	
143			X	
143			X	PCV 471M SIGNAL JPR TO 60TB2-138-B

THIS SHEET INACTIVE
NO LONGER REQ'D

05824	E	1114573
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4 3 2 1

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REV	DATE	DESCRIPTION	APPROVED
A	11-14-68	SEE A DCN	
B	11-14-68	SEE B DCN	
C	11-14-68	SEE INCORP DCN	
D	11-14-68	SEE DCN	
E	11-14-68	SEE DCN	
F	11-14-68	SEE DCN	
G	11-14-68	SEE G DCN	

- NOTES:
- INTERPRET DWG PER STANDARDS PRESCRIBED IN MIL-D-70327.
 - TO BE USED IN CONJUNCTION WITH THE FOLLOWING DRAWINGS: 1114308
09
13
15
1114289
1115332
 - PRESSURE(S) P_{E2} IS A LOOP FEEDBACK DERIVED FROM ENGINE MODEL.

QTY REQD	SYM	CODE	IDENT	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	UNIT	ZONE	ITEM NO
UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES										
DRAWN BY: R. J. ROBERTS										
CHECKED BY: J. J. ROBERTS										
DESIGNED BY: J. J. ROBERTS										
STRESS BY: J. J. ROBERTS										
MATERIAL PROCESS BY: J. J. ROBERTS										
TREATMENT BY: J. J. ROBERTS										
FINISH BY: J. J. ROBERTS										
PART ACT: CALC										
ON: THRU										
PART: NEXT										
NEXT: FINAL										
NEXT: ASBY										
USED ON: APPLICATION										
EFFECTIVE SERIAL NO										
REASON DATA										
DRAWING LEVEL										
SIMILAR TO										
UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES										
DRAWN BY: R. J. ROBERTS										
CHECKED BY: J. J. ROBERTS										
DESIGNED BY: J. J. ROBERTS										
STRESS BY: J. J. ROBERTS										
MATERIAL PROCESS BY: J. J. ROBERTS										
TREATMENT BY: J. J. ROBERTS										
FINISH BY: J. J. ROBERTS										
PART ACT: CALC										
ON: THRU										
PART: NEXT										
NEXT: FINAL										
NEXT: ASBY										
USED ON: APPLICATION										
EFFECTIVE SERIAL NO										
REASON DATA										
DRAWING LEVEL										
SIMILAR TO										

05824 1114329

SWITCHING UNITS A1 AND A2 (RACK 67)

SECTION III

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1. DESCRIPTION AND PURPOSE

1.1 Introduction

This operation and maintenance instruction manual contains the general description, installation procedure, theory of operation, maintenance instructions, and troubleshooting procedures for Switching Units A1 and A2, which are part of the Test Simulation System, Test Stand Control System (TSCS) for ETS-1.

1.2 General Description

The Switching Assemblies, A1 (Part Number 1114542) and A2 (Part Number 1114545), provide the capability to switch various Process System and Engine Control System functions between the OPERATE and SIMULATE modes. The two assemblies were manufactured at Von Karman Center, Aerojet-General Corporation, Azusa, California.

1.2.1 Functional Description

Switching Units A1 and A2 contain relays which perform the simulation switching. The units also provide the 28 v dc to the switching relay within the unit and to the other racks within the TSCS containing the operate/simulate relays. The nomenclature + D1 bus is the OPERATE/SIMULATE mode bus, and the + D2 bus is the TOTAL SIMULATE mode bus.

1.2.2 Physical Description

Refer to AGC Drawings 1114542 and 1114545 for a hardware description.

1.3 Interface

Switching Units A1 and A2 interface with all external signals by means of five chassis-mounted Bendix connectors on each switching unit. Refer to AGC Running Lists 1115826 and 1115827 for signal interface and location information. Modulok information is shown on AGC Drawing 1115711.

1.3.1 Unit

Each unit is slide mounted to Rack 67.

1.3.2 Signal

Refer to paragraph 2.4 for a signal description.

1.3.3 Power Requirements

(a) 28 v dc Test Cell Building direct.

1.3.4 Physical

Overall dimensions of Units A1 or A2 chassis are 19.00 inches wide, 20.0 inches long, and 7.0 inches high.

1.4 Applicable Documents

1.4.1 Drawings

Refer to Tables 1 and 2 for a list of applicable drawings.

TABLE 1

A-1 ASSEMBLY SWITCHING UNIT DRAWING CONFIGURATION

<u>Drawing Number</u>	<u>Title</u>
1114542-9	Switching Unit Assembly, A-1; ETS-1, TSCS
1114543-19	Terminal Board
1114543-29	Terminal Board
1114543-39	Terminal Board
1114544	Schematic Diagram A-1 Switching Unit Assembly

TABLE 2

A-2 ASSEMBLY SWITCHING UNIT DRAWING CONFIGURATION

<u>Drawing Number</u>	<u>Title</u>
1114545-9	Switching Unit Assembly A-2; ETS-1, TSCS
1114543-19	Terminal Board
1114543-49	Terminal Board
1114543-59	Terminal Board
1114543-69	Terminal Board
1114547	Schematic Diagram A-2 Switching Unit Assembly

1.4.2 Specifications

Refer to NDC-118.

1.4.3 Component Documents

D3315 - Chassis Electronic Equipment, Zero Pak Products Co.

1.4.4 Cable Tab Sheets

Refer to the following AGC tab sheets for signal termination:

- (a) 1117527
- (b) 1117526
- (c) 1117525
- (d) 1117528

2. INSTALLATION AND OPERATION

2.1 Safety Precautions

Before installing or removing units make sure the + 28 v dc power is OFF in Rack 67 and the CTE console.

2.2 Installation

Switching Units A1 and A2 shall be installed in the Test Cell Building in accordance with AGC Drawing 1115685. Connect input and output circuits in accordance with AGC Drawing 1115951.

2.3 Adjustment and Calibration

Not required.

2.4 Control Operation

The following signals are switched by relays within each assembly:

(a) Switching Unit A-1

- (1) D1 power bus (operate/simulate mode signal)
- (2) D2 power bus (total simulate mode signal)
- (3) RSV 201 valve command and valve position signals
- (4) RSV107 valve command and valve position signals
- (5) RSV454/460 valve command and valve position signals
- (6) RSV458/459 valve command and valve position signals
- (7) RSV545 valve command and valve position signals
- (8) PCV251 valve command and valve position signals
- (9) PCV472 valve command and valve position signals

- (10) PCV471 valve command and valve position signals
- (11) RSV78 valve command and valve position signals
- (12) Log count rate command signal
- (13) TPCV valve command signal
- (14) PSV valve command signal
- (15) TPA parameters command signal
- (16) Neutronic command signal
- (17) Drum command signal
- (18) Engine temperature/pressure command signal.

(b) Switching Unit A-2

- (1) D1 power bus (operate/simulate mode signal)
- (2) D2 power bus (total simulate mode signal)
- (3) FE52 output signal
- (4) FE12 output signal
- (5) FT15 output signal
- (6) FT415 output signal
- (7) PT484 output signal
- (8) PT101 output signal
- (9) PT103 output signal
- (10) PT194 output signal
- (11) PT473 output signal
- (12) PT475 output signal
- (13) PCV517 valve command and valve position signals
- (14) TT45 output signal
- (15) TT495 output signal
- (16) TT28 output signal
- (17) TT474/496 output signal
- (18) TT55 output signal
- (19) PT891 output signal
- (20) TT881 output signal

- (21) Turbine speed output signal
- (22) TPA parameters output signal
- (23) SCRAM output signal.

2.5 Checkout

The switching units are not intended to be operated independent of the associated TSCS consoles and racks located in the Control Point and Test Cell Buildings. Refer to the following system operations instructions:

- (a) Process Control System
- (b) Simulation System

3. THEORY OF OPERATION

3.1 General

The switching units control the mode of the relays which control the signals listed in paragraph 2.2. The switching relays control the destination of the command signal and/or measured signal to the TSS or to the individual control circuit. The condition of the switching relays, energize/nonenergize, is indicated on Rack 01L.

3.2 Detailed (Refer to Schematics 1114544 and 1114547)

The switching relays in Switching Units A-1 and A-2 are energized by + 28 v dc from the Test Cell Building. The relays in each switching unit that control the condition of DC busses + D1 and + D2 are energized by + 28 v dc from the Control Point Building.. All relays within the units are protected by arc-suppression diodes. There are two +28-v dc control busses in each switching unit; they are designated +D1 and +D2. Each bus is energized by two pairs of relay contacts connected in parallel. The PANEL POWER ON switch, located on the Simulation Panel, energized the K1 relay which in turn energized the +D1 bus. The Simulation Panel contains a lamp which indicates the relay condition. The TOTAL SIMULATE switch located on the Simulation Panel, or the SIMULATE lock switch located on the CTE console energized the K2 relay which in turn energized the +D2 bus.

A typical transducer switching circuit is shown in Figure 1. Switching relay KA is energized by +28 v dc through the individual OPERATE/SIMULATE switch or from the D2 bus (TOTAL SIMULATE). Two pairs of form "C" contacts of relay KA are used; one set shows the condition of the relay on the Simulation Panel (OPERATE/SIMULATE), the other pair receives the signal from the output of the transducer signal conditioning amplifier or from the Simulation System and sends it to the Process Control System.

Figure 1 - Typical Transducer Switching Circuit

A typical analog valve switching circuit is shown in Figure 2. The switching relays, KA (actuator simulated) and KB (real actuator), are energized by +28 vdc from the TCB. The energizing voltage is applied through the OPERATE/SIMULATE switch located on the Simulation Panel. Relay KA can also be energized by +28 v dc from the D2 bus. Four pairs of Form "C" contacts of relay KA and three pairs of normally opened contacts of relay KB are used to perform all switching functions.

One set of normally open contacts of relays KA and KB operates an indicator circuit to show the condition of each relay. The condition of the relay is shown by indicator lights on the Simulation Panel (Operate/Simulate). One set of form "C" contacts of relay KA receives the valve demand signal and sends the signal to the valve actuator or to the TSS (valve simulation and valve logic section). A set of normally open contacts of KB also receives the valve demand signal and sends it to the TSS valve logic section (if KB is energized). A set of form "C" contacts and a pair of normally open contacts of KA relay send the valve position, real valve or simulated valve signals, to the Process Control System. A set of normally open contacts of KB also receives the valve position and sends it to the flow simulation section when relay KB is energized.

A typical binary valve switching circuit is shown in Figure 3. Switching relay KA is energized by +28 v dc from the TCB. The energizing voltage is applied through the OPERATE/SIMULATE switch located on the Simulation Panel. Relay KA can also be energized by +28 v dc from the +D2 bus. Four pairs of form "C" contacts are used to perform the binary valve switching functions.

One set of the form "C" contacts operates on indicator circuit to show the condition of the switching relay. The condition of the relay is shown by an indicator light on the Simulation Panel. The second set of contacts receives the valve demand signal from the Process Control System and sends it to the valve or to the TSS (analog and logic sections). The third set of contacts sends the valve open signal to the Process Control System. This signal

Figure 2 - Typical Analog Valve Switching Circuit

Figure 3 - Typical Binary Valve Switching Circuit

originates from the real valve or from the simulated valve. The fourth set of contacts sends the valve closed signal to the Process Control System. This signal also originates from the real valve or from the simulated valve.

Figure 4 shows a typical circuit when the switching relay is located remotely in another chassis. The switching relay is energized with TCB +28 v dc from the TCB. The energizing voltage is applied through the OPERATE/SIMULATE switch located on the Simulation Panel. The switching assembly contains the switching mode logic from each of these switching relays.

Figure 4 - Typical Circuit when Switching Relay is in Another Chassis

4. MAINTENANCE

4.1 General Maintenance

Periodic tightening of chassis connectors is the minimal routine maintenance required in the air-conditioned environment of the Test Cell Building. Preventive and corrective maintenance should be performed by a skilled technician.

4.2 Adjustment and Calibration

Not required.

4.3 Troubleshooting

Table 3 lists the most probable failures, the most probable cause of the failures, and the corrective action for troubleshooting the switching assemblies. Refer to AGC Drawings 1115826, A1 Assembly Running List, and 1115827, A2 Assembly Running List, when performing point-to-point circuit continuity checks.

4.3.1 Troubleshooting Technique

Voltage measurements should be made using a 20,000 ohms per volt meter or equivalent. Diodes should be tested with an ohmmeter.

TABLE 3

SWITCHING ASSEMBLIES A1 AND A2 TROUBLESHOOTING CHART

<u>Failure</u>	<u>Probable Cause</u>	<u>Corrective Action</u>
1. No Power On D1 bus	1a. Rack 67 28 v dc not ON	1a. Turn on each Rack 67 28 v dc circuit breaker
	b. Panel Power ON switch (Simulation Panel) not ON	b. Turn Panel Power ON
	c. Relay K1 not operating properly	c. Replace K1 relay
	d. Arc-suppression diode shorted	d. Replace diode
2. No Power ON D2 bus	2a. Same as 1a	2a. Same as 1a
	b. TOTAL SIMULATE switch (Simulation Panel) not ON	b. Depress TOTAL SIMULATE switch
	c. Relay K2 malfunctioned	c. Replace K2 relay
	d. Arc-suppression diode shorted	d. Replace diode
3. SIMULATE/OPERATE indicator does not change state when switched	3a. Relay malfunction	3a. Replace relay
	b. Steering diode open	b. Replace diode
	c. Arc-suppression diode shorted	c. Replace diode
4. D1 and D2 bus at same time	4a. One or more steering diodes shorted	4a. Replace diode
5. Valve on transducer indication on the consoles wrong	5a. Switching relay contacts malfunctioning	5a. Replace relay

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NOTES:

1. REMOVE ALL BURRS & SHARP EDGES.
2. 125° ALL MACHINED SURFACES UNLESS OTHERWISE NOTED.
3. METAL STAMP WITH PART NO 1115542-1
4. PRIME AND PAINT PER AGC-SPEC 60274

QTY REQD	SYM	CODE IDENT	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	UNIT WT	ZONE	ITEM NO.
			-1	2" x 3/8" BAR	H. R. STEEL	43TM-A7			

LIST OF MATERIALS

	UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DECIMAL TOL XX ± .03 ANGULAR TOL ± 2° XXX ± .010 DO NOT SCALE DRAWING										DRAWN FISCUS 9/12/65	DATE 9/12/65		AEROJET-GENERAL CORPORATION SACRAMENTO, CALIFORNIA ROCKET ENGINE OPERATIONS - NUCLEAR			
	TREATMENT										DESIGN P. B. B. 10/11/65	10/11/65		TITLE	ARM-LINKAGE MOBILE TABLE		
	FINISH 4										STRESS 10/11/65	10/11/65		CODE IDENT NO.	DWG NO.		
	PART DASH NO. 05824										PRODUCT ASSURANCE 10/11/65	10/11/65		SIZE C	1115542		
WTS APPD										DESIGN ACTIVITY APPD 9/27/65		SCALE 1/2		RELEASE DATE 10-13-65		SHEET	

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REVISIONS			
SYM	ZONE	DESCRIPTION	DATE APPROVED

- NOTES: 1. REMOVE ALL BURRS & SHARP EDGES.
 2. INTERPRET DWG PER STANDARDS PRESCRIBED IN MIL-D-70327.
 3. METAL STAMP PART NO 1115544-1.
 4. ²⁵⁰ALL MACHINED SURFACES.
 5. PRIME AND PAINT PER AGC-SPEC 60274.

QTY REQD	SYM	CODE IDENT	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	UNIT WT	ZONE	ITEM NO.
			-1		3.00 DIA BAR LC STEEL	ASTM-A-7			

	UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DECIMAL TOL XX ± .03 ANGULAR TOL ± 2° XXX ± .010 DO NOT SCALE DRAWING										DRAWN <i>MG Martin</i> DATE <i>7-25-65</i> CHECKED <i>P. Balch</i> <i>9-23-65</i> DESIGN <i>W. C. F. C.</i> <i>10-11-65</i> PROJECT <i>W. C. F. C.</i> <i>9-27-65</i>		AEROJET-GENERAL CORPORATION SACRAMENTO, CALIFORNIA ROCKET ENGINE OPERATIONS - NUCLEAR	
	TREATMENT										STRESS <i>W. C. F. C.</i> <i>10-11-65</i> MAT'L/PROCESS <i>W. C. F. C.</i> <i>10-11-65</i> FAB/MFG-ENGR. <i>W. C. F. C.</i> <i>10-11-65</i> PRODUCT ASSURANCE <i>W. C. F. C.</i> <i>10-11-65</i> DESIGN ACTIVITY <i>W. C. F. C.</i> <i>9-27-65</i>		TITLE CAP, END MOBILE TABLE.	
	PART DASH NO. <i>11155079</i> <i>POC.MTS</i> PART DASH NO. <i>11155079</i> <i>POC.MTS</i> QTY REQD PER ASSY <i>4</i> APPLICATION <i>1</i>										CODE IDENT NO. 05824 DWG SIZE C DWG NO. 1115544		SCALE <i>1/1</i> RELEASE DATE <i>10-13-65</i> SHEET <i>3-4-66</i>	
	PART DASH NO. <i>11155079</i> <i>POC.MTS</i> PART DASH NO. <i>11155079</i> <i>POC.MTS</i> QTY REQD PER ASSY <i>4</i> APPLICATION <i>1</i>										FINISH <i>5</i> SIMILAR TO		SCALE <i>1/1</i> RELEASE DATE <i>10-13-65</i> SHEET <i>3-4-66</i>	

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NOTES:

1. REMOVE ALL BURRS & SHARP EDGES.
2. ELECTRO ETCH WITH PART NO. 1115545 AND APPLICABLE DASH NO.
3. ALL MACHINED SURFACES UNLESS OTHERWISE NOTED.
4. BLACK OXIDE COAT PER MIL-C-13924

QTY	REGO	SYM	CODE	IDENT	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	UNIT	ZONE	ITEM NO.
-2					2.187-558	PRECISION SHAFT	C-1045 STL	Q-QS-633			
-1					2.187-558	PRECISION SHAFT	C-1045 STL	Q-QS-633			

REON		PART NO.		ACT. CALC.		ON THRU		PART NO.		NEXT FINAL		NEXT ASSY		USED ON	
WTS APPD		EFFECTIVE SERIAL NO.		USAGE DATA		QTY REQD PER ASSY		APPLICATION		DRAWING LEVEL		SIMILAR TO			

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- NOTES:**
1. REMOVE ALL BURRS & SHARP EDGES.
 2. METAL STAMP WITH PART NO. 1115547-1
 3. ALL MACH. SURFACES
 4. PRIME AND PAINT PER AGC SPEC 60274 EXCEPT THREADED HOLES.

REVISIONS			
SYM	ZONE	DESCRIPTION	DATE

QTY REQD	SYM	CODE IDENT	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	UNIT WT	ZONE	ITEM NO.
			-1	2 x 2 x 1/8 ANGLE	STR 57L	ASTM A-7			

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DECIMAL TOL XX = .03 XXX = .010 DO NOT SCALE DRAWING	DRAWN FJSCUS CHECKED DBULT DESIGN PROJECT TREATMENT FINISH	DATE 9-18-65 10-11-65 10-11-65 10-11-65 10-11-65 10-11-65	LIST OF MATERIALS AEROSPACE CORPORATION JAZZAMENTO, CALIFORNIA ROCKET ENGINE OPERATIONS - NUCLEAR	TITLE ANGLE - MOBILE TABLE	CODE IDENT NO. 05824	DWG NO. 1115547	SCALE 1	RELEASE DATE 10-15-65	SHEET 3-2-66 GSE
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REON	PART DASH NO.	ACT. CALC	ON	THRU	PART DASH NO.	NEXT FINAL	NEXT ASSY	USED ON	APPLICATION	DRAWING LEVEL	1
	WTS AND	WEIGHT	EFFECTIVE SERIAL NO.	USAGE DATA		QTY REQD PER ASSY					

☒ ADCN ☐ DCN DATE 1-18-66	DRAWING CHANGE NOTICE AEROJET-GENERAL CORPORATION Sacramento, California CODE IDENT NO. 05824	DWG LEVEL 1 DRAWING NUMBER 1115547 CHG LTR A FABRICATION AFFECTED ☒ YES ☐ NO SHEET 1 OF 1
DRAWING TITLE ANGLE - MOBLE TABLE		
REASON FOR CHANGE		APPROVALS
☒ FACILITATE FABRICATION ☐ CUSTOMER CHANGE	☐ DESIGN CHANGE ☐ DESIGN ERROR	☐ DRAFTING ERROR ☐ OTHER
DRAWN BY MARTIN PROJECT 1-20-66 DESIGN J. D. Jones STRESS-WEIGHT		FAB/MFG ENG DESIGN ACTIVITY CHECKED BY W. HILTZ DATE 1-20-66
RELEASED D. Calabrese DATE 1/20/66		

1. F/D: 13C

(IS)

2.00

(WAS)

1.50

**.37 x 45°
4 PLACES**

2. F/D: 13B

**.37 R
2 PLACES**

INCORPORATED BY	DATE	CHECKED BY	DATE
	//		//

☒ ADCN	☐ DCN	DATE 1-20-66
INCORPORATED BY	DATE / /	☒ DRAWING
CHECKED BY	DATE / /	☐ STANDARD
		☐ SPECIFICATION

DOCUMENT CHANGE NOTICE
 AEROJET GENERAL CORPORATION
 SACRAMENTO, CALIFORNIA
 CODE IDENT. NO. 05824

DWG LVL 1	DOCUMENT NUMBER 1115547	CHG LTR B
DOCUMENT TITLE ANGLE - MOBILE TRIPLE		SHEET 1 OF 1

REASON FOR CHANGE				APPROVALS			
FACILITATE FABRICATION	DESIGN CHANGE	DRAFTING ERROR	OTHER TO PREVENT JAGS FROM CATCHING IN MAIN HOLE	DES. ACTIVITY	PREPARED BY A. TOW	STRUCTURE/STRESS R. H. Hiltz	MATERIALS P. E. Hiltz
CUSTOMER CHANGE	DESIGN ERROR	ADDITION DESIGN INFO.		DESIGN R. H. Hiltz	CHECK U. Hiltz	PRODUCTION	RELEASE D. Hiltz
							DATE 1/20/66
							CUSTOMER

1. F/D, ADDED R AS SHOWN:

— .06 R

RACK 01 LEFT SIMULATION PANEL

SECTION IV

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1. DESCRIPTION AND PURPOSE

1.1 Introduction

This operation and maintenance instruction manual contains the general description, installation procedures, theory of operation, maintenance instructions, and troubleshooting procedures for the Rack 01L Simulation Panel.

1.2 General Description

This section covers the Simulation Panel, Part Number 1114551-9, mounted in Rack 01L.

1.2.1 Physical Description

For the physical location of the Simulation Panel see Rack 01L Assembly Drawing 1114532-9. For detail panel layout, see Figure 1.

1.3 Interface

1.3.1 Panel Interface

The panel interfaces with the modules of Rack 01L.

1.3.2 Signal Interface

The Simulation Panel interfaces with the CTE console, Rack 46, Rack 47, Rack 48, Rack 49, Rack 60, Rack 63 and Rack 67.

1.4 Applicable Documents

1114532-9	Rack 01L Assy
1114533	Running List - Rack 01L

TSCS SIMULATION PANEL

LAMP
VERIFY

COOLDOWN SYSTEM

FT415	PCV471	TT586	PT473	RSV78	RSV460 RSV454		RSV201	FT15	PCV251	PT3 475/587
OPER SIM	OPER SIM	OPER SIM	OPER SIM	OPER SIM	OPER SIM		OPER SIM	OPER SIM	OPER SIM	OPER SIM
GHe					GHe & GH ₂			GH ₂		
RSV 07	TT28	PT101	FT12	PCV472	TT495	PT4 4	RSV458 RSV459	PT103 PT891	TT474 496 881	CSV
OPER SIM	OPER SIM	OPER SIM	OPER SIM	OPER SIM	OPER SIM	OPER SIM	OPER SIM	OPER SIM	OPER SIM	OPER SIM
LN ₂								COMMON MANIFOLD		
TT55	PT194	FE52	PCV517	RSV545	TT510 TT511	PT580				
OPER SIM	OPER SIM	OPER SIM	OPER SIM	OPER SIM	OPER SIM	OPER SIM				
LN ₂										

ENGINE SYSTEM

PSV	TPA PARAM	TPCV		TURBINE SPEED	ENG TEMP PRESS
OPER SIM	OPER SIM	OPER SIM		OPER SIM	OPER SIM
	LOG COUNT RATE	DRUMS	NEUT	SCRAM IND	
	OPER SIM	OPER SIM	OPER SIM	OPER SIM	

INDICATOR POWER	PRESS MODE INHIBIT	TEMP MODE INHIBIT	POWER OVERRIDE	TPO ERROR	ISS CONTROL
	ACT BYP	ACT BYP	MAN AUTO	ACT BYP	REM LOC

PANEL POWER ON	PANEL POWER OFF	I. C.	ENGINE COMPUTE	HOLD	RESET	SW POSITION
						TOTAL SIM

Figure 1 - Panel Arrangement - Simulation Panel

1114551-9	Simulation Panel Assy
1114554	Schematic - Simulation Panel
1115825	Running List - Simulation Panel
1114552	Simulation Panel Detail

2. INSTALLATION AND OPERATION

2.1 Safety Precautions

Before installing or removing the Simulation Panel, make sure +28 VDC power is OFF in Rack 01L and the CTE console.

2.2 Installation

The Simulation Panel shall be mounted in Rack 01L in accordance with Drawing 1114532-9.

2.3 Adjustment and Calibration

Calibration is not required for the Simulation Panel.

2.4 Control Operations

The Simulation Panel controls and monitors the (operate/simulate) condition of the following functions:

2.4.1 Functions - Test Simulation

1. GHe Cooldown Line

- a. FT415
- b. PCV471
- c. TT586
- d. PT473
- e. RSV78

2. GHe and GH_2 Cooldown Line
 - a. RSV460/454
3. GH_2 Cooldown Line
 - a. RSV201
 - b. FT15
 - c. PCV251
 - d. PT3/475/587
4. LH_2 Cooldown Lines
 - a. RSV107
 - b. TT28
 - c. PT101
 - d. FT12
 - e. PCV472
 - f. TT495
 - g. PT484
 - h. RSV458/459
5. Common Cooldown Manifold
 - a. PT103/891
 - b. TT474/496/881
 - c. CSV
6. LN_2 Cooldown Line
 - a. TT55
 - b. PT194
 - c. FE52
 - d. PCV517
 - e. RSV545
 - f. TT510/511
 - g. PT580

7. Engine System
 - a. PSV
 - b. TPA Parameters (Pump Discharge Temperature and Pressure, LH₂ Flow, Pump Inlet Pressure, Turbine Inlet Temperature and Pressure)
 - c. TPCV
 - d. Turbine Speed (One and Two)
 - e. Engine Temperature/Pressure (Station 26 and 30, Chamber Temperature and Pressure, Reflector Temperature, Tie Rod Temperature, Station 1/2 + 1 Temperature)
 - f. Log Count Rate
 - g. Drums
 - h. SCRAM Indicator
8. Panel Power
 - a. Panel Power OFF
 - b. Panel Power ON
9. TSS Mode Control
 - a. Local/Remote Control (ISS Control)
 - b. Initial Condition (I.C.)
 - c. Engine Compute
 - d. Hold
 - e. Reset (Master)
10. Indicator Power
 - a. Indicator Power ON
 - b. Switch Position

11. Total Simulate
12. Lamp Verify (provides a means to verify panel bulbs)

2.4.2 Functions - Active/Bypass and Manual/Auto

The Simulation Panel controls and monitors the active/bypass and manual/auto conditions of the following functions. These functions are not part of the Test Simulation System.

- (a) Pressure Mode Inhibit, Active/Bypass
- (b) Temperature Mode Inhibit, Active/Bypass
- (c) Power Override, Manual/Auto
- (d) TPO Error, Active/Bypass

2.5 Checkout

The Simulation Panel can be checked out individually using the Schematic Diagram in Figure 2. This panel is not intended to be operated independent of the associated TSCS consoles and racks located in the Control Point and Test Cell Buildings. Refer to the following Operation and Maintenance Manuals:

1. RN-S-0349 - Process System Control
2. RN-S-0376 - Test Stand Control Subsystem
3. Section III of this document
4. RN-S-0450 - Engine Control

Figure 2 - Schematic Diagram - Simulation Panel (AGC Drawing No. 1114554)

3. THEORY OF OPERATION

3.1 General

The Simulation Panel controls and monitors test stand and engine hardware simulator or operate condition.

3.2 Input/Output Circuits

All indicators and switches operate from 28 VDC.

3.2.1 Simulation Panel (Refer to Schematic 1114554, Figure 2)

All switch light assemblies, single and three-way split, operate on Control Point Building 28 VDC. Power to the panel (excluding TSS mode control) is controlled by the CTE console. When the CTE console is in the Operate/Simulate mode, the Panel Power OFF indicator is illuminated through the normally closed switch contacts on the Power ON switch assembly. The Panel Power is energized by depressing the Panel Power ON switch which is a momentary type with a 28 VDC holding coil. The Panel Power ON switch picks up the POWER ON relay and energizes the panel's 28 VDC bus with +28 VDC from the CPB. The Panel Power OFF switch, a momentary type, controls the de-energization of the Power ON switch holding coil. The Power Panel ON indicators are controlled by a pair of normally open relay contacts (+ D1 bus) located within the switching units (Assembly A1, and Assembly A2 within Rack 67) in the TCB. The top two indicator lights are controlled by operation of the D1 bus in the A1 assembly; the bottom two indicator lights are controlled by the operation of the D1 bus in the A2 assembly.

The TOTAL SIMULATE switch, an alternate action type, also controls the panel's 28 VDC bus through the panel's diode logic. The TOTAL SIMULATE indicators are controlled by a pair of normally open relay contacts (+D2 bus) located within the A1 and A2 switching assemblies. Energizing the +D2 bus will put all panel functions, refer to paragraph 2.4, into the simulate mode. The TOTAL SIMULATE mode can be energized by the CTE console mode control key switch.

All indicators in the three-way split switch lamps are energized by panel power, DPB +28 VDC, and controlled by the following:

- a. Top two indicator lamps by the switch's normally open pair of contacts.
- b. The bottom right indicator lamp is controlled by a pair of normally open contacts of the Operate/Simulate relay located within the various racks in the TCB.
- c. The bottom left indicator is controlled by a pair of normally closed contacts of the Operate/Simulate relay.

All of the above switches, alternate action type, control the TCB +28 VDC (+ D1 bus) to the Operate/Simulate relays.

The TSS control switch light assembly operates the same as the above, only the nomenclature is different. REMOTE is analogous to OPERATE, and LOCAL is analogous to SIMULATE. These indicator lamps are energized by CPB +28 VDC. The REMOTE switch position gives mode control to the TSS in the TCB. The LOCAL switch position gives mode control to the TSS, Rack 60 in the TCB, from Rack 01L in the CPB.

The TSS mode control switch lamp assemblies, momentary with-holding coils, are connected in a bailing circuit so that only one mode can be energized at a time. This is accomplished by interrupting the holding coil of the energized switch with the mode switch to be energized. The mode switch indicators are energized by CPB +28 VDC. This voltage is controlled by the mode relay in the TSS.

The indicator power switch lamp assembly momentary is connected to the Simulate/Operate switches so that switch positions can be verified prior to operation of the Simulation Panel.

The engine system active/bypass and auto/manual switch lamp assemblies, alternate action type, three-way split switch lamps, control CP 28 VDC and monitor parameter are listed in paragraph 2.4.2.

The lamp verify circuits apply CP +28 VDC to all lamps on the panel. A diode logic module is mounted on each switch lamp assembly.

4. MAINTENANCE

4.1 General Maintenance

Periodic dusting and cleaning are the minimal routine maintenance required in the air-conditioned environment of the Control Point Building. Preventative and corrective maintenance should be performed by a skilled electronic technician.

4.2 Adjustment

None Required

4.3 Calibration

None Required

4.4 Troubleshooting

Table 1 lists the most probable failures, the most probable cause of failures, and the recommended corrective action for troubleshooting the panel. Refer to Schematic Diagram in Figure 2 when performing point-to-point circuit checks.

TABLE 1

SIMULATION PANEL TROUBLESHOOTING CHART

<u>Failure</u>	<u>Probable Cause</u>	<u>Corrective Action</u>
1. No Lamp Verify on any panel.	1. Circuit Breaker OFF	1. Turn circuit breaker ON.
2. Indicator lamps ON without lamp verify switch energized	2. Short between Lamp Verify bus and a control indication circuit	2. Clear shorted wire, modulok or diode.
3. Indicator Lamp not ON	3. a. Burned out lamp b. Indicator lamp circuit open	3. a. Replace lamp b. Verify wiring between the lamp and the indicator's relay N/O contact and back to CPB 28-v common.
4. Panel Power OFF Indicator Lamp OFF (Simulation Panel)	4. a. CTE console key switch not in OPERATE/SIMULATE position	4. a. Put key switch in correct position and assure 28 v dc power is on CTE.
5. Panel Power ON Indicator lamp does not go ON (Simulation Panel)	5. a. Faulty switch module on A2SDS54 b. Switching Units A1 and A2 assemblies, Rack 67 K1 relay do not operate.	5. a. Replace module b. Check continuity between 01L and Rack 67
6. Only top or bottom of Power Indicator ON lamp goes on (Simulation Panel)	6. a. Top two lamps are controlled by a pair of N/O contacts, A1 assembly, of the K1 relay. b. Bottom two lamps are controlled by a pair of N/O contacts, A2 assembly, of the K1 relay.	6. a. Verify K1 relay operation. b. Verify K1 relay operation

TABLE 1 (cont.)

<u>Failure</u>	<u>Probable Cause</u>	<u>Corrective Action</u>
7. More than one of the TSS mode switch light assemblies are illuminated (Simulation Panel)	7. a. Switch contacts are faulty	7. a. Verify switch operation of A2SDS55, 56, 57, and 58
8. No mode switch lamp illumination when switch is energized	8. a. Relay in Rack 60 is not operating correctly	8. a. Verify relay operation
9. Three-way split switch lamp when operated Top lamps are OFF	9. a. Faulty switch assembly	9. a. Replace switch assembly
10. Bottom right-hand lamp is out, three way split, when switch is operated	10. a. Broken wire between OIL and rack in the TCB	10. a. Verify circuit continuity
	b. Relay in TCB did not operate	b. Verify relay operation
11. Bottom left-hand lamp is out, three-way split, when switch is de-energized	11. a. Same as 10a	11. a. Same as 10a
	b. Same as 10b	b. Same as 10b
12. Both bottom lamps ON, three-way split when switch is operated.	12. a. Two or more relays should be energized by switch	12. a. Verify each associated relay operation