

NanoArc Master Technical Architecture and Configuration Baseline

ACE RevA Freeze - Master Revision 1.2 with RevB/RevC Compatibility Roadmap

NanoArc Project

2026-06-26

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Document Control

Field	Value
Document identifier	NA-MASTER-001
Baseline	RevA Freeze / Master Revision 1.2
Date	2026-06-26
Status	Configuration-controlled architecture baseline
Scope	ACE controller, operator interface, software architecture, I/O contracts, parts baseline, verification and revision roadmap
Total merged length	219 pages

Configuration rule: This master baseline is the highest-authority NanoArc ACE document. If an appended supporting manual conflicts with this Part I baseline, Part I prevails. Parts II, III and IV are aligned A.1 implementation baselines. Superseded A.0 concepts are retained only in revision records and source history, never as parallel firmware requirements.

Revision Record

Revision	Date	Status	Summary
1.2 / RevA Freeze	2026-06-26	Firmware-consistency freeze	Replaces Parts III and IV with aligned A.1 manuals; freezes pin/address/event/code registries and removes remaining contradictory implementation guidance.
1.1 / RevA Freeze	2026-06-26	Superseded corrective issue	Replaced Part II with NA-CSHID-001 A.1, but retained outdated A.0 hardware and PVN component manuals.
1.0 / RevA Freeze	2026-06-26	Superseded master issue	Initial merged issue; Part II retained the preliminary ARCEXEC/ARCVM architecture.
RevB	Reserved	Future controlled revision	Characterized machine interfaces, sensors, harnesses and EMC evidence.
RevC	Reserved	Future controlled revision	Production mechanical and manufacturing refinement; logical interfaces remain stable.

Master Volume Map

Part	Content	Normative status	Final PDF start
I	Integrated RevA master baseline and firmware consistency register	Highest authority	1

Part	Content	Normative status	Final PDF start
II	NA-CSHID-001 Control System and HID Architecture Manual A.1	Normative; aligned with Part I	41
III	NA-ACEHW-001 Hardware and Operator-Panel Manual A.1	Normative; aligned with Parts I and II	62
IV	NA-ACEPVN-001 Program, Routine, Verb, Noun and Operator-Flow Manual A.1	Normative; implementation code registry	93
V	Apollo 15 CMC parsed reference	Informative source extract	131
VI	Apollo 15 CMC program procedures	Informative source extract	147

Canonical Firmware Contracts

1. **PROG is not a physical key.** Program selection is performed with V37, followed by the two-digit Program code and ENTR.
2. **PRO remains a physical key.** It means proceed/approve the active prompt and is distinct from ENTR.
3. **There is no dedicated ACK key.** Informational/internal display release uses KEY REL; prompt acceptance uses ENTR or PRO; corrected annunciations use RSET.
4. **Program alarms are inspected with V05 N09.** N09 preserves first, second and latest alarm semantics. KEY REL restores the prior nonblocking display in normal cases.
5. **A Program is not a machine state.** The old SAFE + PROGRAM_REQUEST -> PROGRAM Supervisor transition is rejected. Program selection belongs to ProgramExecutive; safety authority remains in Supervisor.
6. **Panel matrix is 4 rows x 5 columns.** It uses nine expander lines and retains PRO while deleting PROG and ACK.
7. **Three MCP23017 expanders are the system baseline:** panel input, panel output and machine noncritical I/O.
8. **A shared open-drain expander interrupt is used** for the input expanders; no extra direct pin is spent per expander.
9. **The external SPI ADC is the primary analog-acquisition interface.** Nano ADC pins are not allocated as the machine sensor census.
10. **External FRAM stores mutable profiles, calibration, logs and counters.** Internal EEPROM is restricted to board identity and boot-critical fallback.
11. **There is no ARCVM or executable profile bytecode in RevA.** Profiles are typed data; guided flows are native Program/Routine sequence tables.
12. **N09 is the only first/second/latest alarm tuple.** N50 is current detail and N51 is persistent history/cursor data.
13. **There is no alarm-acknowledgement event.** Prompt responses are ENTR, PRO, KEY REL or RSET according to the active descriptor.
14. **The EventQueue remains bounded but its final capacity is evidence-driven.** Firmware must record overflow and high-water measurements before release.

1. Executive Summary

NanoArc is frozen for RevA as an AGC-inspired, Nano Every based control system whose primary job is to supervise machine facts, validate operator intent, manage Programs and routines, control low-voltage preparation interfaces, and request a tightly bounded output window through a separate fail-safe path.

The baseline is intentionally modular. The operator panel and noncritical machine discretetes are expanded over I2C; analog telemetry is acquired over SPI; hard-safe and hard-real-time signals remain direct; profiles, alarm records and calibration data live in external FRAM; and output authorization remains impossible to obtain from the display or command parser alone.

The Nano Every remains viable, but the direct pin margin is effectively exhausted. This is acceptable because the design now has stable expansion contracts and three spare growth mechanisms: unused expander lines, reserved external ADC channels, and a HAL boundary that permits a later controller migration without changing the panel or power-module interface.

The most important Apollo-derived lesson is structural rather than cosmetic. Programs, routines, display ownership, prompts, alarm storage and operator commands are separate concepts. ACE therefore keeps machine safety state, active Program, Program phase, authorization state and display owner orthogonal.

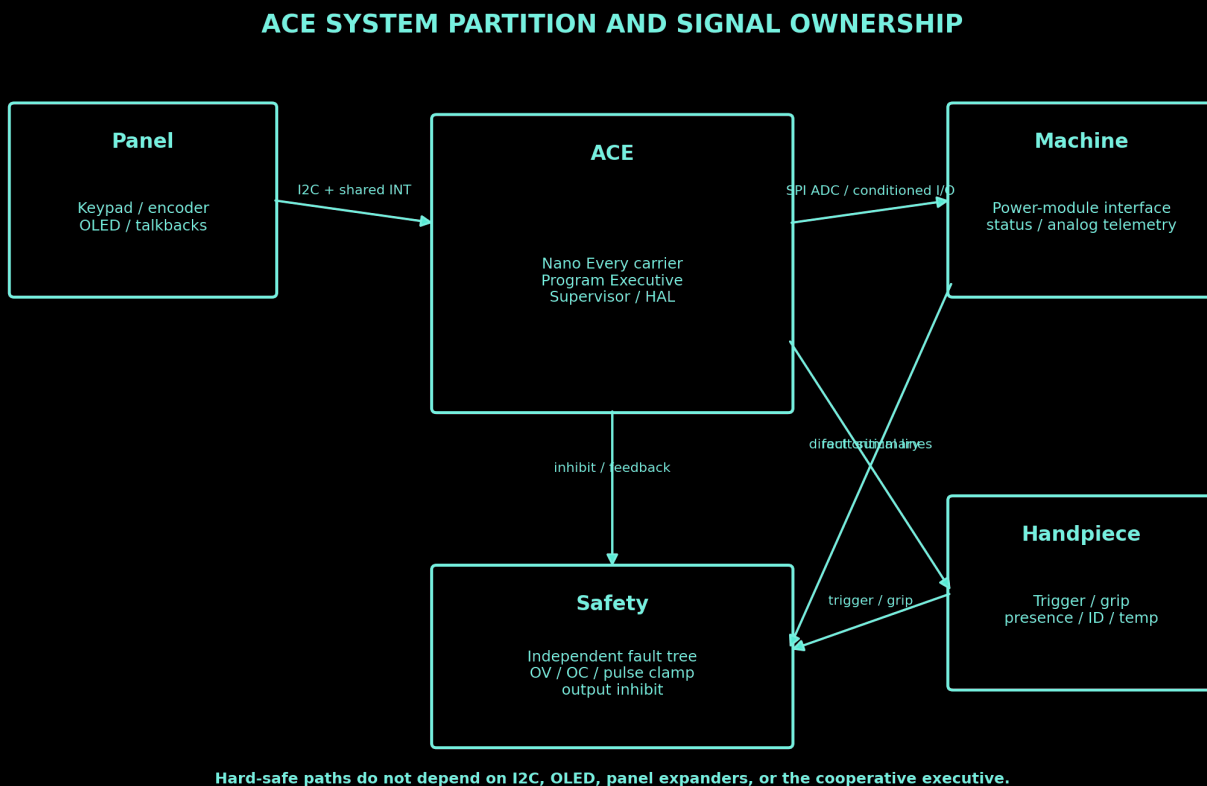


Figure 1: System partition and signal ownership.

2. Scope and System Boundary

This master document is authoritative for the low-voltage ACE controller and its human interface. It defines the controller carrier, panel, software executive, command model, sensor and switch interfaces, low-voltage machine I/O, diagnostics, verification, and revision management.

The energy-storage and high-current output stages are **interfaces**, not construction procedures, in this baseline. ACE sees conditioned measurements, discrete status facts, and bounded command inputs/outputs. Raw hazardous nodes do not enter the controller or operator panel.

Included

- Nano Every carrier and resource ownership
- Operator panel, display, keypad, encoder, talkbacks and sounder
- Direct safety/interlock and timing signals
- Shared I2C control bus, SPI analog acquisition and FRAM
- Complete signal and pin census
- Programs, routines, Verbs, Nouns, prompts and display arbitration
- Fault aggregation, alarm storage and restart behavior
- Firmware architecture, test strategy and acceptance criteria
- RevA/RevB/RevC compatibility constraints

Excluded or deferred

- Final energy-storage sizing and high-current switching design
- Raw power-stage conductor, fuse, busbar and electrode construction
- Final sensor transfer functions before hardware characterization
- Final enclosure mechanics and compliance certification
- Any operating procedure that bypasses the verified interlock chain

3. Frozen Design Invariants

1. All outputs initialize inhibited after reset, brownout, watchdog expiry and impossible state.
2. The display, keypad, encoder, I2C bus and profile layer cannot directly authorize or time an output.
3. Hard trips and the maximum pulse window have independent hardware enforcement.
4. Trigger, grip, arm, hard-safe, enclosure interlock, overvoltage trip, overcurrent trip, fault summary, output feedback, pulse request and inhibit are direct signals.
5. Program selection uses V37; there is no PROG key.
6. PRO, ENTR, KEY REL, CLR and RSET have non-overlapping meanings.
7. V05 N09 is the standard alarm-code retrieval path.
8. KEY REL restores the previous nonblocking display when a temporary internal or priority display has taken ownership.
9. Programs are long-lived procedures; routines are reusable bounded activities; neither is a machine safety state.
10. No heap allocation, recursion or unbounded queue is permitted in release executive code.
11. Descriptor tables and constant strings live in flash; persistent operational data live in external FRAM.
12. All external wiring enters through protection and conditioning. Raw I2C is kept local to the ACE/panel enclosure.
13. The RevA direct-pin map is frozen unless a formal change request demonstrates equal or safer behavior.

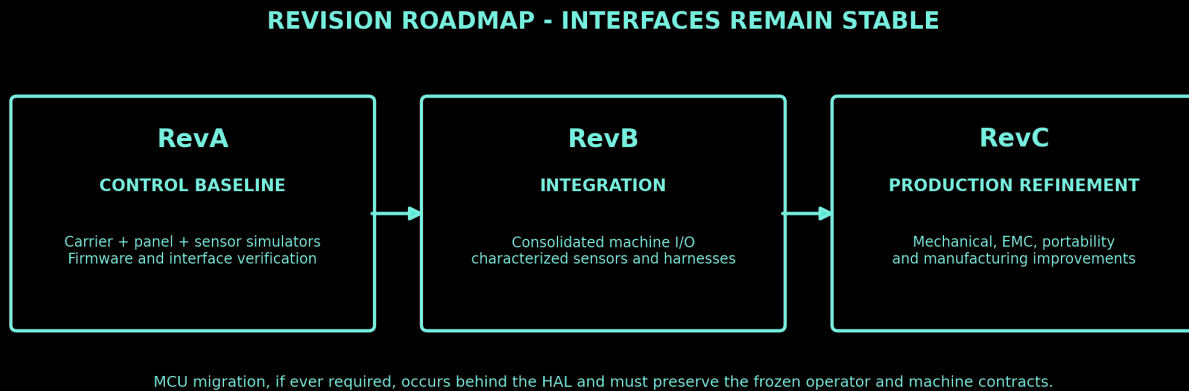


Figure 2: Revision roadmap.

4. Revision Strategy

RevA - control-module baseline

RevA proves the carrier, panel, command model, firmware architecture, sensor simulators, storage, fault aggregation and machine-interface loopback without requiring an energized output stage. Breakout modules and a carrier PCB are acceptable.

RevB - integration baseline

RevB consolidates the machine I/O and analog front end, characterizes actual sensors, freezes connector pinouts, demonstrates bus/EMC robustness and validates all hardware thresholds. It preserves the RevA panel and software contracts.

RevC - production refinement

RevC addresses enclosure, portability, manufacturing, environmental margins and service access. A controller migration is permitted only if RevA external contracts and operator semantics remain source-compatible at the HAL and descriptor levels.

5. Controller Platform and Resource Envelope

The Arduino Nano Every / ATmega4809 is the frozen RevA controller. The project relies on its 48 KB flash, 6 KB SRAM, 256 B internal EEPROM, TWI/I2C, SPI, multiple 16-bit timers, RTC/PIT, watchdog, event system and interrupt-capable general-purpose I/O [S1].

The board remains adequate only when hidden library costs are controlled. The OLED must use a page or tile buffer when possible; descriptor strings belong in flash; serial formatting must not execute in the critical path; and timer ownership must be audited against the Arduino core [S2].

Resource	Baseline use	Gate
Flash	Kernel, drivers, descriptors, display and diagnostics	< 42 KB release image
SRAM	Queues, active program, page buffer, snapshots and stack	< 3 KB static allocation
EEPROM	Board ID and emergency constants only	Do not use for logs
External FRAM	Profiles, calibration, alarms, counters and restart record	32 KB baseline
I2C	Panel, OLED, FRAM and reserved sensor/control targets	Local bus only
SPI	External ADC	D10-D13 reserved
Timers	One pulse timer, RTC/PIT executive tick, core timer audited	No library may claim pulse timer

Resource gates

- Flash warning at 38 KB; architecture review at 42 KB.
- Static SRAM warning at 2.5 KB; architecture review at 3.0 KB.
- At least 2 KB effective runtime/stack margin in representative tests.
- One hardware timer is permanently reserved for the output-window service.
- TX/RX remain available for service and recovery diagnostics.

6. System Hardware Partition

The ACE controller is divided into the operator panel, ACE carrier, machine I/O/analog front end, direct safety path, handpiece interface and conditioned power-module interface.

- **Operator panel:** low-speed human interface only.
- **ACE carrier:** Nano Every, FRAM, bus pull-ups, reset/watchdog, direct-pin conditioning and HAL boundary.
- **Machine I/O:** third MCP23017, SPI ADC, analog buffers, comparator outputs and fault latch.
- **Handpiece interface:** trigger, grip, presence, analog ID and temperature; all conditioned at the ACE connector.
- **Power-module interface:** only bounded commands and conditioned facts. Raw power nodes remain outside ACE.
- **Safety path:** discrete comparator/fault logic and maximum pulse clamp can inhibit the downstream driver without firmware cooperation.

7. Bus and Address Architecture

I2C is a shared addressed bus, not a set of one-device slots. The design nevertheless treats it as one electrical fault domain and keeps it physically local. The baseline allows existing sensor/control hardware to occupy reserved addresses while the panel and storage remain on the same bus.

Address / bus	Device	Status
0x20	MCP23017 panel input	Required
0x21	MCP23017 panel output	Required
0x22	MCP23017 machine I/O	Required
0x3C	128 x 64 OLED	Required; exact controller module verified at procurement
0x40-0x47	Machine sensor/control reservations	At least one address reserved for existing or future sensor/control hardware
0x50	MB85RC256V FRAM	Required
0x68	Optional RTC	DNP in RevA unless wall-clock evidence is required
SPI CS D10	External ADC	Required

All I2C pull-ups are fitted at one controlled location on the ACE carrier. Daughterboard pull-ups are DNP by default. The controller performs explicit presence checks for required devices and provides a bounded bus-recovery sequence before declaring the bus failed.

The external ADC uses SPI so analog acquisition does not add latency or fault coupling to the operator/control I2C bus.

8. Final Operator-Panel Baseline

The operator panel is inspired by DSKY interaction discipline, not by a literal reproduction. Program, Verb and Noun codes remain visible; prompts flash only when a response is required; physical talkbacks present the most important state facts independently of OLED page ownership.

Program selection is entered as **V37 E ## E**. A dedicated PROG key is therefore unnecessary and is removed. PRO remains because it has a different semantic role: approve/proceed through an active prompt without pretending a data word was entered.

There is no generic ACK key. Temporary internal displays are released with KEY REL, result or data prompts use ENTR/PRO as specified, and eligible annunciations are reset with RSET only after the cause has cleared.

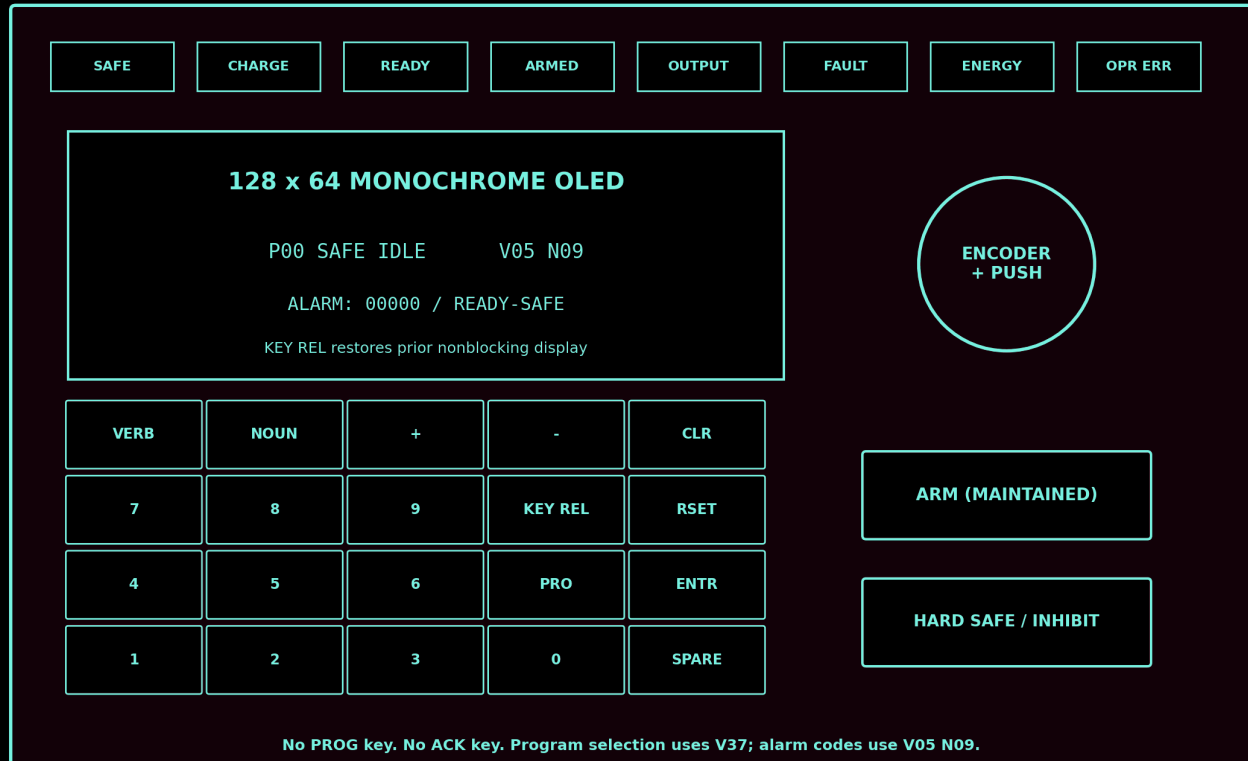


Figure 3: Frozen RevA operator panel.

Key matrix

Row	C0	C1	C2	C3	C4
R0	VERB	NOUN	+	-	CLR
R1	7	8	9	KEY REL	RSET
R2	4	5	6	PRO	ENTR
R3	1	2	3	0	SPARE

The 4 x 5 matrix consumes nine expander lines. RevA rejects multi-key rollover and impossible combinations. Per-key diodes remain a RevB option if field testing shows contamination or ghosting risk.

Key meanings

- **VERB / NOUN:** select the next two-digit command field.
- **+ / -:** select a sign for signed data; they do not arm or authorize.

- **CLR:** clear staged data or back out of an incomplete entry.
- **PRO:** approve/proceed through the active Program prompt.
- **ENTR:** commit a command, accept a loaded component, or answer an ENTR prompt.
- **KEY REL:** release an internal/priority display and restore the previous nonblocking display, or return to the Program default page when no prior display exists.
- **RSET:** clear an eligible annunciation after the underlying condition is gone; it never bypasses a fault.
- **Encoder:** browse lists and edit bounded values; encoder push is local selection, not a substitute for ENTR or PRO.

Talkbacks

SAFE, CHARGE, READY, ARMED, OUTPUT, FAULT, ENERGY and OPR ERR occupy one full 8-bit output port. FAULT and ENERGY should have a hardware override path or independent local indication where practical.

9. DSKY-Informed Display and Alarm Semantics

The Apollo CMC reference confirms that the DSKY has no PROGRAM key, V37 changes the major Program, V05 N09 displays alarm data, and KEY REL relinquishes an interrupted display [S10]. ACE adopts those interaction principles.

Program selection

1. Operator enters V37 ENTR.
2. Command Executive opens a two-digit Program entry prompt.
3. Operator enters the Program code and ENTR.
4. ProgramExecutive validates existence, present safety state, transition inhibits and required hardware facts.
5. Accepted requests transition the active Program; rejected requests set OPR ERR and preserve the current Program.

Alarm retrieval

V05 N09 displays:

- R1: first alarm since reset,
- R2: second alarm since reset,
- R3: latest alarm.

RSET may clear eligible annunciation state after the cause is absent, but the most recent alarm and persistent history remain in FRAM. A richer chronological history is exposed through a separate service Noun.

Display ownership

The Display Executive stores the current operator context before a higher-priority internal display takes ownership. KEY REL restores that context in nonblocking cases. Blocking safety facts may remain visible or continue to own the display until their clearing rule is satisfied, but V05 N09 remains available whenever safe to present.

10. Orthogonal State Model

ACE maintains separate dimensions:

- **MachineState:** BOOT, SAFE, STANDBY, OPERATE, FAULT.
- **ProgramCode:** P00, P01, P02, P06, P10 and others.
- **AuthorizationState:** INHIBITED, PREPARED, ARMED.
- **ProgramPhase:** Program-specific step/state.
- **DisplayOwner:** operator, Program, monitor, safety or alarm.

This corrects the early implementation that represented **PROGRAM** as a machine state. `program_request` is routed to ProgramExecutive, not interpreted by Supervisor as a direct state transition.

Supervisor owns safety state and authorization. ProgramExecutive owns active Program and Program phase. CommandExecutive owns staged Program/Verb/Noun entry. DisplayExecutive owns visible context and restoration. AlarmManager owns active/latched alarm presentation and persistent records.

11. Firmware Architecture and Current Implementation

The current firmware already provides a tested vertical slice:

- `Event` is an 8-byte fixed ABI record.
- `EventQueue` is a fixed-capacity FIFO with rejection rather than overwrite.
- `Supervisor` handles boot completion, fault assertion and conditional corrected-fault reset processing.
- `Executive::run_once()` pops one event and returns `IDLE`, `HANDLED` or `UNHANDLED`.
- Host self-tests and the Nano Every PlatformIO build run together.

Required migration

1. Remove or retire `MachineState::program`.
2. Add strongly typed `ProgramCode`, `VerbCode`, `NounCode`, `PromptCode` and `AlarmCode` wrappers.
3. Add `ProgramExecutive` with `P00` as the default `Program` after successful startup.
4. Route `program_request` to `ProgramExecutive`.
5. Add `CommandBuilder` for `V37` and `Verb/Noun/data` entry.
6. Add `DisplayContext` with one interrupted-context slot in `RevA`.
7. Add `PromptManager` responses for `ENTR`, `PRO`, `KEY REL` and `RSET`; no `ACK` response exists.
8. Add descriptor tables in flash and FRAM-backed persistent records.
9. Add HAL interfaces for direct pins, expanders, ADC and storage.

12. Program Catalogue

Code	Program	Purpose
P00	SAFE IDLE	Default command entry, status and safe monitoring
P01	STARTUP SELF-TEST	Internal boot verification
P02	RECOVERY	Reset-cause interpretation and safe reconstruction
P06	STANDBY / POWER-DOWN	Low-activity safe mode
P10	SINGLE OPERATION	One prepared and authorized operation
P11	REPEAT JOB SESSION	Bounded repeated operations
P12	DRY RUN / SIMULATION	Full logic with physical output inhibited
P20	PROFILE SELECT / REVIEW	Browse and activate profiles
P21	PROFILE EDIT	Edit and validate a working profile
P22	MATERIAL CALIBRATION	Future controlled characterization
P23	SENSOR CALIBRATION	Low-voltage channel calibration
P24	TOOL CONFIGURATION	Tool identity and electrode configuration
P30	SYSTEM STATUS	Read-only monitoring
P31	PANEL TEST	Panel and annunciator test
P32	I/O DIAGNOSTICS	Read direct facts and bounded I/O tests
P33	ALARM / RESTART REVIEW	Alarm and reset history
P34	STORAGE INTEGRITY	FRAM record and checksum verification
P40	SERVICE MODE	Restricted maintenance
P90	DEVELOPMENT HARNESS	Synthetic events; excluded from release

13. Verb Catalogue

Code	Class / command	Meaning
V01-V06	Display	One-shot display of selected noun components
V11-V16	Monitor	Continuously refreshed display
V21-V25	Load	Stage one, two or three noun components
V32	Recycle / reject	Return to an earlier safe prompt or reject provisional data
V34	Terminate	End an eligible routine/program path
V35	Panel test	Exercise lamps/display/sounder in a bounded mode
V36	Controlled restart	Fresh-start request with restart policy
V37	Change Program	The only normal program-selection command
V50	Please perform / checklist	Prompted operator action
V63	Proceed / accept result	ACE-specific result acceptance where descriptor permits

14. Noun Catalogue

Range / code	Frozen role	Representative components
N01-N08	Executive and command	machine state, active Program, active profile, command, prompt, option, checklist, executive resources
N09	Alarm-code tuple	first, second and latest alarm since reset
N10-N19	Power, safety and hardware facts	supply, energy, temperatures, interlocks, output path, readiness, bus, panel and reset status
N20-N29	Profile and configuration	identity, materials, action parameters, tool, repetition and validity
N30-N39	Operation and result	active operation, measured result, cooldown and sequence progress
N40-N49	Measurement and calibration	analog channels, sensor status and working calibration values
N50	Current alarm detail	code, source/severity and active/latched state
N51	Persistent alarm history	selected record/cursor, code and timestamp/sequence
N52-N59	Counts, inhibits, restart and service	alarm counts, inhibit reason, restart record, event/history cursor and service request
N60-N69	Diagnostics and identity	build, storage, device and bus diagnostics
N80-N85	Calibration working set	bounded temporary calibration values

Every Noun descriptor declares zero to three typed components, access policy, format, unit, scale, range, validity source and storage class. No firmware module may infer a Noun layout from the numeric code alone.

15. Program and Routine Flow Rules

Programs are long-lived procedures with explicit entry assumptions, phases, prompts, fault behavior and exit rules. Routines are reusable bounded activities requested by Programs or the executive.

P00 SAFE IDLE

- Default Program after successful startup or normal termination.
- Accepts command entry, status displays, profile selection and diagnostics.
- Maintains hardware inhibit and disallows output authorization.

P10 SINGLE OPERATION

1. Verify current machine state and direct safety facts.
2. Load or confirm the active profile.
3. Validate profile, tool identity, sensor validity and hardware readiness.
4. Request preparation while remaining inhibited.
5. Enter READY-SAFE when all conditions are met.
6. Observe physical ARM, grip and trigger facts.
7. Request Supervisor authorization.
8. Timed-output service owns the bounded pulse window.
9. Capture result, reassert inhibit, perform cooldown/readiness evaluation.
10. Return to P00 or enter FAULT.

P10 never writes the gate hardware directly. It issues requests through the Supervisor and timed-output service.

R07-style automatic sequencing

RevA reserves a table-driven sequence controller for P11 and later guided workflows. Each row specifies the Program/routine request, completion event, timeout, cancel path and fault fallback. This adopts the useful organizational principle of the Apollo MINKEY controller without importing spacecraft-specific behavior.

16. Signal Classification

- **Class A:** hard-safe or hard-real-time. Direct pin and/or hardware path.
- **Class B:** supervised machine control/status. Direct or machine expander depending latency and consequence.
- **Class C:** slow analog and housekeeping. External ADC or polled expander.
- **Class D:** operator interface, storage, logging and service. Panel expanders, FRAM and OLED.

No Class A signal is mediated solely by an I2C expander.

17. Frozen Direct Pin Map

Nano pin	Signal	Direction	Ownership / rationale
D2	FAULT_SUM	Input	Direct open-drain aggregate fault; immediate safe response
D3	TRIP_OV	Input	Independent bank overvoltage comparator
D4	ARM_SW	Input	Maintained physical authorization; direct
D5	HARD_SAFE_SW	Input	Dominant physical safe control; direct
D6	GRIP_SW	Input	Handpiece enabling contact; direct
D7	TRIGGER_SW	Input	Final operator request; direct
D8	OUTPUT_FB	Input	Command/actual cross-check
D9	PULSE_CMD	Output	Timer-owned request to downstream pulse hardware
D10	ADC_CS	Output	SPI ADC chip select
D11	SPI_MOSI	Output	External ADC
D12	SPI_MISO	Input	External ADC
D13	SPI_SCK	Output	External ADC
A0	HW_INHIBIT	Output	Default-safe hardware inhibit request
A1	CHARGE_ENABLE	Output	Supervised preparation request
A2	ENCLOSURE_INTLK	Input	Direct enclosure/service interlock
A3	EXPANDER_INT	Input	Shared open-drain interrupt from input expanders
A4	I2C_SDA	Bus	OLED, expanders, FRAM, reserved sensor/control devices
A5	I2C_SCL	Bus	OLED, expanders, FRAM, reserved sensor/control devices
A6	HANDPIECE_PRESENT	Input	Direct presence indication
A7	TRIP_OC	Input	Independent current-trip comparator
AREF	RESERVED	-	External reference or emergency revision reserve
TX/RX	SERVICE_UART	Bus	Build, test and recovery diagnostics; not field I/O

18. Panel Input Expander - MCP23017 at 0x20

Pin	Signal
GPA0	KEY_COL0
GPA1	KEY_COL1
GPA2	KEY_COL2
GPA3	KEY_COL3
GPA4	KEY_COL4
GPA5	KEY_ROW0
GPA6	KEY_ROW1
GPA7	KEY_ROW2
GPB0	KEY_ROW3
GPB1	ENC_A
GPB2	ENC_B
GPB3	ENC_SW
GPB4	PANEL_PRESENT
GPB5	SPARE_IN0
GPB6	SPARE_IN1
GPB7	SPARE_IN2

19. Panel Output Expander - MCP23017 at 0x21

Pin	Signal
GPA0	TB_SAFE
GPA1	TB_CHARGE
GPA2	TB_READY
GPA3	TB_ARMED
GPA4	TB_OUTPUT
GPA5	TB_FAULT
GPA6	TB_ENERGY
GPA7	TB_OPR_ERR
GPB0	OLED_RST
GPB1	BUZZER
GPB2	LAMP_TEST
GPB3	PANEL_DIM_OR_ENABLE
GPB4	SPARE_OUT0
GPB5	SPARE_OUT1
GPB6	SPARE_OUT2
GPB7	SPARE_OUT3

20. Machine I/O Expander - MCP23017 at 0x22

Pin	Signal	Direction
GPA0	CHARGER_READY	Input
GPA1	CHARGER_FAULT	Input
GPA2	BLEED_CONFIRM	Input
GPA3	FAN_TACH_OR_GOOD	Input
GPA4	AUX_INTERLOCK	Input
GPA5	SERVICE_KEY	Input
GPA6	POWER_MODULE_PRESENT	Input
GPA7	FAULT_LATCH_VALID	Input
GPB0	BLEED_ENABLE	Output
GPB1	FAN_ENABLE	Output
GPB2	CONTACT_TEST_ENABLE	Output
GPB3	FAULT_LATCH_RESET	Output
GPB4	MACHINE_SPARE0	I/O
GPB5	MACHINE_SPARE1	I/O
GPB6	MACHINE_SPARE2	I/O
GPB7	MACHINE_SPARE3	I/O

21. Analog Acquisition Register

The external ADC interface is frozen; the exact population changes by revision. RevA may use an MCP3208 for the first eight channels and sensor simulators. RevB/C should use a 16-channel device such as ADS7953 or a validated equivalent without changing the HAL channel identifiers.

ADC channel	Signal	Purpose
AIN0	VBANK	Bank voltage telemetry; cross-checks independent OV trip
AIN1	VIN_AUX	Input supply / source telemetry
AIN2	ICHG_MON	Charge current from analog current-sense amplifier
AIN3	IOUT_MON	Output-current monitor from isolated Hall or characterized shunt front end
AIN4	TBANK	Energy-storage temperature
AIN5	TSTAGE	Power-interface temperature
AIN6	TACE	ACE carrier temperature
AIN7	THAND	Handpiece temperature
AIN8	VLOGIC	Logic rail health
AIN9	CONTACT_TEST	Low-energy continuity/contact measurement
AIN10	HANDPIECE_ID	Resistor-coded tool identification
AIN11	VREF_MON	ADC reference monitor
AIN12-15	RESERVED	Future sensors and characterization channels

22. Hardware Fault Aggregation

Independent comparators and hardware supervision feed both the downstream inhibit path and ACE:

- bank overvoltage,
- current trip,
- driver/output feedback mismatch,
- external watchdog expiry,
- maximum-pulse clamp expiry,
- critical thermal trip where fitted,
- enclosure or auxiliary interlock fault.

Open-drain outputs are combined into `FAULT_SUM`. A separate latch captures a source bitmap for V05 N09 and service inspection. ACE responds to `FAULT_SUM` immediately and diagnoses the detailed cause afterward; detailed diagnosis is never required before inhibit is asserted.

The maximum-pulse clamp is independent of the firmware timer. A non-retriggerable monostable such as SN74HC221 is the baseline candidate, with the final RC/window value frozen only after the power-interface requirements are characterized.

23. Component Baseline

The following parts are the frozen preferred families or qualified alternatives for the ACE low-voltage controller. Final procurement substitutions must match voltage, temperature, package, timing and fault behavior.

Function	Recommended part / family	Package / form	Reason
Main controller	Arduino Nano Every ABX00028	Module / 2 x 15 headers	Frozen RevA platform; 48 KB flash, 6 KB SRAM, 256 B EEPROM
Panel input expander	MCP23017-E/SS	SSOP-28 or breakout	Key matrix, encoder, shared interrupt
Panel output expander	MCP23017-E/SS	SSOP-28 or breakout	Eight talkbacks, buzzer, OLED reset, spares
Machine I/O expander	MCP23017-E/SS	SSOP-28	Noncritical status and auxiliary controls
Prototype ADC	MCP3208-CI/P	DIP-16	RevA breadboard-friendly 12-bit, 8-channel SPI ADC
Production ADC	ADS7953SBDBT	TSSOP-38	RevB/C 16-channel, 12-bit SPI ADC with growth margin
ADC reference	REF5025AID	SOIC-8	2.5 V precision reference; monitor with ADC channel
Persistent memory	MB85RC256V	SOIC-8 or breakout	32 KB I2C FRAM for profiles, calibration, alarms and counters
Comparator	LMV331 / LMV393	SOT-23-5 / SOIC-8	Independent OV/OC and threshold outputs
Pulse clamp	SN74HC221	SOIC-16	Independent non-retriggerable maximum pulse window
External watchdog	TPS3431 or TPS3823 family	SOT-23 / VSON	Optional independent MCU supervision for RevB/C
Fault latch	SN74HC573A	TSSOP-20	Captures a fault-source bitmap for post-event inspection
Fault encoder	SN74HC148	SOIC-16	Optional hardware priority code for immediate cause classification
Panel lamp driver	ULN2803A	SOIC-18 / DIP-18	Eight low-side channels for talkbacks
Analog buffer	MCP6004	TSSOP-14 / DIP-14	Low-rate rail-to-rail buffering and filters
Charge-current sense	INA180A2 / INA181 family	SOT-23-5	Analog shunt amplifier feeding external ADC
Output-current sense	ACS770 / ACS758 family	Module / CB package	Isolated Hall candidate; final range after characterization
Temperature sensors	10 k NTC, B=3950	Radial / ring-lug / epoxy probe	Low-cost bank, stage and handpiece monitoring
Local temperature	MCP9700A	SOT-23-3	Optional ACE-board analog temperature
I2C level shift	PCA9306	VSSOP-8	Fit only if a true 3.3 V target is selected

Function	Recommended part / family	Package / form	Reason
I2C isolation	ISO1540	SOIC-8	Not fitted unless an I2C branch leaves the local enclosure
Harness ESD	TPD4E05U06	USON-10	Four-line low-capacitance ESD protection at connectors
Rail TVS	SMBJ5.0A or selected equivalent	SMB	Logic-rail transient clamp after rail review
Logic buck	LMR51430 or qualified module	SOIC/HSOIC or module	12-24 V to 5 V logic rail; final network after EMC review
Optional 3.3 V LDO	TLV75533	SOT-23-5	Only when mixed-voltage devices require it
Display	2.42 in 128 x 64 OLED, SSD1306/SSD1309 class	Panel module	Monochrome, page-buffered rendering
Encoder	Bourns PEC11R-4215F-S0024	Panel encoder	Quadrature plus push
Key switches	6 x 6 mm tactile switches	THT or SMD	19 functional positions plus one spare in 4 x 5 matrix
Panel connectors	IDC 2 x 10 boxed header	2.54 mm THT	Panel harness, keyed and serviceable
Power-interface connector	Molex Micro-Fit 3.0, 12-circuit	THT	Conditioned machine signals only
Handpiece connector	Molex Micro-Fit 3.0, 8-circuit	THT	Trigger, grip, ID, temp, presence and returns
Auxiliary connector	JST-XH, 6-circuit	THT	Enclosure and service functions

24. Connector and Harness Baseline

J-PNL - operator panel

Keyed IDC 2 x 10. Carries local logic power, I2C, shared interrupt, reset/service lines and returns. The panel is inside the controller enclosure.

J-PWR - conditioned machine interface

Molex Micro-Fit 3.0, 12 circuits. Carries only conditioned low-voltage commands and status lines. Raw energy-stage nodes are prohibited.

J-HND - handpiece signals

Molex Micro-Fit 3.0, 8 circuits. Carries trigger, grip, presence, analog ID, temperature, shield/drain and returns. High-current conductors use a physically separate connector and are not part of the ACE signal harness.

J-AUX - enclosure/service

JST-XH, 6 circuits for enclosure interlock, service key, auxiliary fan/status and reserved service functions.

Harness entries receive ESD protection, series impedance and filtering appropriate to their signal class. Shield/chassis termination is kept distinct from analog and logic returns until the defined bonding point.

25. Low-Voltage Power, Reset and EMC

- +5V_LOGIC powers the Nano Every, expanders, FRAM, ADC digital interface and logic.
- +5V_PANEL may be separately filtered or switched for the OLED and talkbacks.
- +3V3_AUX is DNP unless a selected module genuinely requires it.
- The analog reference and analog ground network are routed separately from talkback and digital return currents.
- Every IC receives local decoupling; each board receives bulk capacitance appropriate to its load step.
- Reset holds downstream outputs inhibited through pull-downs or dominant hardware logic.
- Brownout, watchdog and software reset all re-enter P01/P02 and may never restore ARMED.
- I2C and SPI traces remain short and separated from noisy power conductors.
- Connector protection is placed at the connector, not deep inside the board.

26. Memory and Persistence

Internal EEPROM is limited to board identity, immutable calibration fallback and boot-critical constants. External FRAM stores:

- profile directory and profile records,
- sensor calibration coefficients,
- first/second/latest alarm registers,
- chronological alarm and restart records,
- usage counters and service history,
- configuration revision and CRC/version fields.

Each persistent record has a version, length, sequence number and integrity field. Firmware never assumes a record layout without checking its version. RevB/C may expand FRAM capacity without changing record identifiers.

27. Verification and Acceptance

RevA staged verification

1. **Carrier-only:** reset defaults, direct-pin safe states, UART, watchdog and build identification.
2. **Panel:** keypad matrix, encoder, OLED, eight talkbacks, sounder and shared interrupt.
3. **Storage:** FRAM record create/read/update, power-loss simulation and corruption handling.
4. **Analog simulator:** all ADC channel identifiers, range/validity handling and stale-data alarms.
5. **Machine I/O loopback:** third expander, status facts, output defaults and connector pinout.
6. **Fault tree:** each fault source asserts downstream inhibit and `FAULT_SUM`; source latch is readable afterward.
7. **Program flow:** P00/P01/P02/P12/P30/P31/P32/P33 without an energized output stage.
8. **Timing:** pulse service exercised only into a logic-level test fixture; jitter and maximum clamp are measured.
9. **Restart:** no reset path restores preparation, authorization or an unfinished Program action.
10. **Resource gate:** flash, SRAM, stack and queue-watermark evidence recorded.

Acceptance records

- schematic and PCB revision,
- firmware commit and build hash,
- pin/address registry,
- populated options and DNP list,
- test logs and fault-injection results,
- measured rail and timing evidence,
- unresolved deviations and approved waivers.

28. Firmware Implementation Sequence

1. Correct the state model and introduce ProgramCode with P00.
2. Add ProgramExecutive and route program requests away from Supervisor.
3. Add command builder for V37, regular Verb families and typed Nouns.
4. Add PromptManager with ENTR, PRO, KEY REL and RSET responses.
5. Add DisplayExecutive restoration context and V05 N09 alarm display.
6. Add descriptor tables and compatibility validation.
7. Add HAL interfaces for direct pins, MCP23017, ADC and FRAM.
8. Add P01/P02 startup and recovery.
9. Add P12 dry-run and P30/P31/P32/P33 diagnostics.
10. Add P10 only after the low-voltage machine interface and independent clamp are verified.

Every slice includes host tests and the Nano Every build. New hardware drivers receive a simulator or fake implementation before connection to external hardware.

29. Frozen and Deferred Decisions

Frozen for RevA

- Nano Every controller and HAL boundary
- Direct pin map in Section 17
- Three MCP23017 roles and addresses
- SPI external ADC interface and channel identifiers
- I2C FRAM at 0x50
- 4 x 5 keypad with PRO, no PROG and no ACK
- Eight talkbacks including OPR ERR
- V37 program selection, V05 N09 alarm retrieval, KEY REL restoration
- Orthogonal machine/program/authorization/display model
- P00 default Program and descriptor-driven command validation
- Independent fault summary and maximum-pulse clamp requirement

Deferred until characterized hardware exists

- Exact analog divider ratios and calibration coefficients
- Exact current-sensor range and transfer function
- Exact maximum-pulse clamp duration
- Final threshold values for OV, OC and thermal trips
- Final connector shell/keying variants and cable gauges
- Final display module vendor and controller variant
- Optional RTC and I2C isolation population
- RevB production ADC population

30. Firmware Consistency Register

This register prevents superseded vocabulary and allocations from re-entering implementation through old notes, copied headers or partial code branches. Treat the left column as compile-time or review-time forbidden identifiers unless it appears only in a migration test or revision-history comment.

Forbidden or superseded item	Required RevA implementation
<code>MachineState::program</code> or <code>MachineState::PROGRAM</code>	<code>MachineState::OPERATE</code> plus independent <code>ProgramCode</code> and <code>ProgramPhase</code>
Supervisor transition <code>SAFE + PROGRAM_REQUEST -> PROGRAM</code>	Program request routed to <code>ProgramExecutive</code> ;
Physical PROG key	Supervisor evaluates safety/authorization separately
Generic ACK key, <code>AlarmAck</code> , <code>EV_ALARM_ACK</code>	V37E##E: VERB 3 7 ENTR, two Program digits, ENTR
4 x 4 or 5 x 4 keypad	ENTR/PRO prompt responses; KEY REL display release; RSET conditional alarm reset
Seven talkbacks	4 rows x 5 columns; nineteen functional keys plus one SPARE position
Two MCP23017 devices	SAFE, CHARGE, READY, ARMED, OUTPUT, FAULT, ENERGY and OPR ERR
Per-expander direct IRQ pins	0x20 panel input, 0x21 panel output, 0x22 machine I/O
Direct Nano sensor-ADC allocation	Shared open-drain <code>EXPANDER_INT</code> on A3
Profile/log storage in internal EEPROM	SPI ADC on D10-D13; stable logical analog channel IDs
ARCVm, opcode interpreter or executable profile	Versioned and checksummed external FRAM records at 0x50
N08 or N51 as first/second/latest alarm tuple	Typed profile records plus native Program/Routine phase and R07 sequence tables
V58 acknowledge or V72 duplicate reset	N09 only; N50 current detail; N51 persistent history entry/cursor
Unbounded display stack	V05 N09 retrieval and physical RSET after source clear
Fixed queue capacity accepted without evidence	One interrupted <code>DisplayContext</code> plus bounded pending-owner arbitration
Raw I2C beyond the local ACE/panel enclosure	Compile-time bounded queue with overflow alarm and measured high-water evidence
	Conditioned discrete/analog harness interfaces; local I2C only

30.1 Firmware-source rules

1. Hardware pin numbers, I2C addresses, code values and logical channel IDs are defined once in configuration headers generated or manually transcribed from the frozen registries.
2. Numeric pin literals are prohibited outside the HAL and board-definition layer.
3. Program, Verb, Noun, Prompt and Alarm numeric values are strongly typed; implicit integer interchange is prohibited.
4. Descriptor tables are immutable flash data. Mutable state stores descriptor IDs, not pointers to temporary objects.
5. Every command compatibility combination and every writable Noun validator has a host test.
6. Every Program phase has an explicit normal exit, timeout exit, terminate policy and fault fallback.
7. Every bus transaction has a finite deadline and returns a typed validity/error result.
8. Restart tests prove that preparation, authorization and unfinished actions are never reconstructed as active.

30.2 Pre-merge audit patterns

Release tooling should fail or require explicit waiver when source files outside tests/history contain any of these patterns:

```
MachineState::program
EV_ALARM_ACK
AlarmAck
ARCVm
PROG_KEY
```

ACK_KEY
NOUN_08_ALARM_TUPLE
NOUN_51_ALARM_TUPLE
MCP23017_COUNT 2

The exact symbol spelling may differ, so review also searches semantic equivalents. A waiver must cite a migration or compatibility test and may not create a runtime path.

Appendix A. Quick-Look I2C and SPI Register

Interface	Assignment
I2C 0x20	Panel input MCP23017
I2C 0x21	Panel output MCP23017
I2C 0x22	Machine I/O MCP23017
I2C 0x3C	OLED
I2C 0x40-0x47	Reserved machine sensor/control devices
I2C 0x50	FRAM
I2C 0x68	Optional RTC
SPI D10-D13	External ADC

Appendix B. Source Register

ID	Source	Use
S1	Arduino Nano Every datasheet / pinout	Controller resources, pin exposure, voltage and memory limits
S2	ArduinoCore-megaAVR timing implementation	Core timer ownership and timekeeping assumptions
S3	Microchip MCP23017 datasheet	GPIO expansion, addressing, interrupts, reset behavior
S4	TI ADS7953 datasheet	Production 16-channel SPI ADC candidate
S5	Microchip MCP3208 datasheet	RevA prototype 8-channel SPI ADC candidate
S6	Fujitsu MB85RC256V datasheet	I2C FRAM capacity, endurance and bus behavior
S7	TI LMV331 / LMV393 datasheets	Independent comparator paths for OV/OC and threshold facts
S8	TI SN74HC221 datasheet	Independent maximum-pulse clamp candidate
S9	TI TPD4E05U06 datasheet	Harness-entry ESD protection
S10	Apollo 15 Delco manual, CMC section	DSKY semantics, V37, V05 N09, KEY REL, program/routine flow
S11	Virtual AGC Assembly-Language Manual	Executive, interpreter, memory and interrupt inspiration
S12	NanoArc NA-CSHID-001 RevA.1	Revised control-system and HID architecture; supersedes A/0.1
S13	NanoArc NA-ACEHW-001 A.1	Frozen hardware, panel, direct-pin, expander, ADC and FRAM baseline
S14	NanoArc NA-ACEPVN-001 A.1	Frozen Program, Routine, Verb, Noun, prompt, alarm and event registry

Appendix C. References

External technical references

- S1: Arduino Nano Every datasheet and official pinout: <https://docs.arduino.cc/resources/datasheets/ABX00028-datasheet.pdf>
- S2: ArduinoCore-megaAVR timing source: <https://github.com/arduino/ArduinoCore-megaavr>
- S3: MCP23017 datasheet: <https://ww1.microchip.com/downloads/aemDocuments/documents/APID/ProductDocuments/Data-Sheet-DS20001952.pdf>
- S4: ADS7953 datasheet: <https://www.ti.com/lit/ds/symlink/ads7953.pdf>
- S5: MCP3208 datasheet: <https://ww1.microchip.com/downloads/aemDocuments/documents/APID/ProductDocuments/Data-Sheet-DS90C03.pdf>
- S6: MB85RC256V datasheet: <https://www.fujitsu.com/us/Images/MB85RC256V-DS501-00017-3v0-E.pdf>
- S7: LMV331 comparator family: <https://www.ti.com/product/LMV331>
- S8: SN74HC221 monostable: <https://www.ti.com/product/SN74HC221>
- S9: TPD4E05U06 ESD protector: <https://www.ti.com/lit/ds/symlink/tpd4e05u06.pdf>
- S10: Apollo 15 Delco manual, supplied project copy ([A15Delco.pdf](#)).
- S11: Virtual AGC Assembly-Language Manual, supplied project copy.

Included NanoArc controlled documents

- S12: NA-CSHID-001, Control System and Human-Interface Architecture Manual, Revision A.1.
- S13: NA-ACEHW-001, ACE Hardware and Operator-Panel Architecture Manual, Revision A.1.
- S14: NA-ACEPVN-001, ACE Program, Routine, Verb, Noun and Operator-Flow Architecture Manual, Revision A.1.

Appendix D. Configuration Precedence

1. NA-MASTER-001 Part I integrated baseline.
2. Approved engineering change orders and revision-specific addenda.
3. Included NanoArc component manuals, except explicitly superseded sections.
4. CMC and Virtual AGC references as design inspiration and source traceability.
5. Historical brainstorming notes, A.0 component manuals and early parts lists as non-normative background only.

A future RevB or RevC release must publish a new master baseline rather than silently editing component manuals. The revision record must identify every changed external interface, pin, code, prompt or storage record.

NANOARC

Control System and Human-Interface Architecture Manual

Revision A.1 - Integrated Executive and Memory Baseline

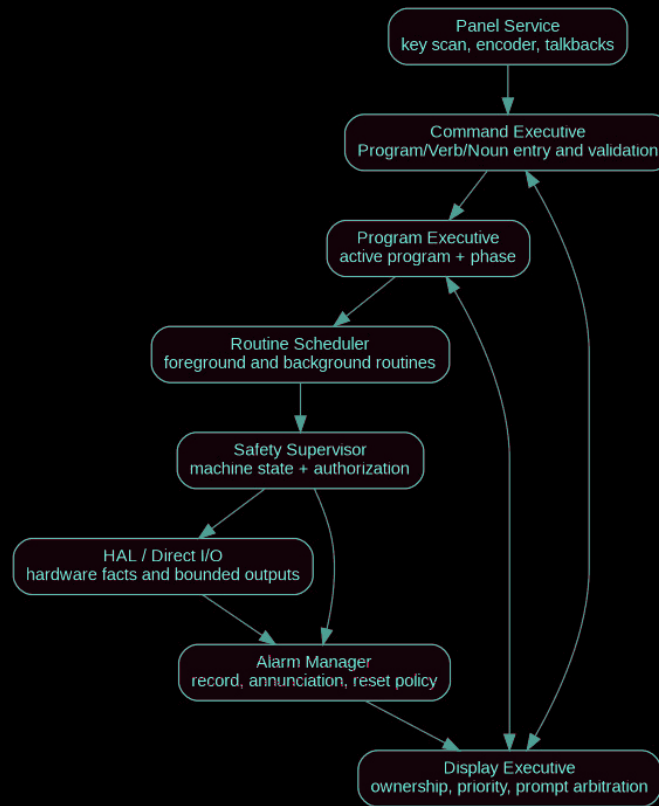


Figure 1. Revised ACE ownership boundaries: safety, Program, command, display and hardware abstraction are separate.

Field	Value
Document identifier	NA-CSHID-001
Revision	A.1 / Master Revision 1.2
Date	2026-06-26
Status	RevA frozen control-system architecture
Supersedes	Revision A / 0.1 dated 2026-06-19
Controller	Arduino Nano Every / ATmega4809
DESIGN NOTE: This manual defines the ACE low-voltage control computer and operator-interface architecture. It does not define construction or operating procedures for the energy stage.	

Document Control and Contents

Revision	Date	Status	Summary
A / 0.1	2026-06-19	Superseded	Initial ARCEXEC, ARCVMM, rotary-menu and preliminary memory model.
A.1	2026-06-26	Frozen	Integrates orthogonal state model, Program/Verb/Noun interface, final panel, full I/O census, FRAM, external ADC and descriptor-based execution.

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DESIGN NOTE: Configuration precedence: NA-MASTER-001 Part I remains the highest authority. This A.1 manual is the detailed control-system implementation baseline and is written to agree with that master baseline.

1. Purpose, Scope and Authority

ACE supervises operator intent, machine facts, Program execution, display ownership, persistent records and low-voltage requests while ensuring that output authorization remains bounded, observable and fail-safe.

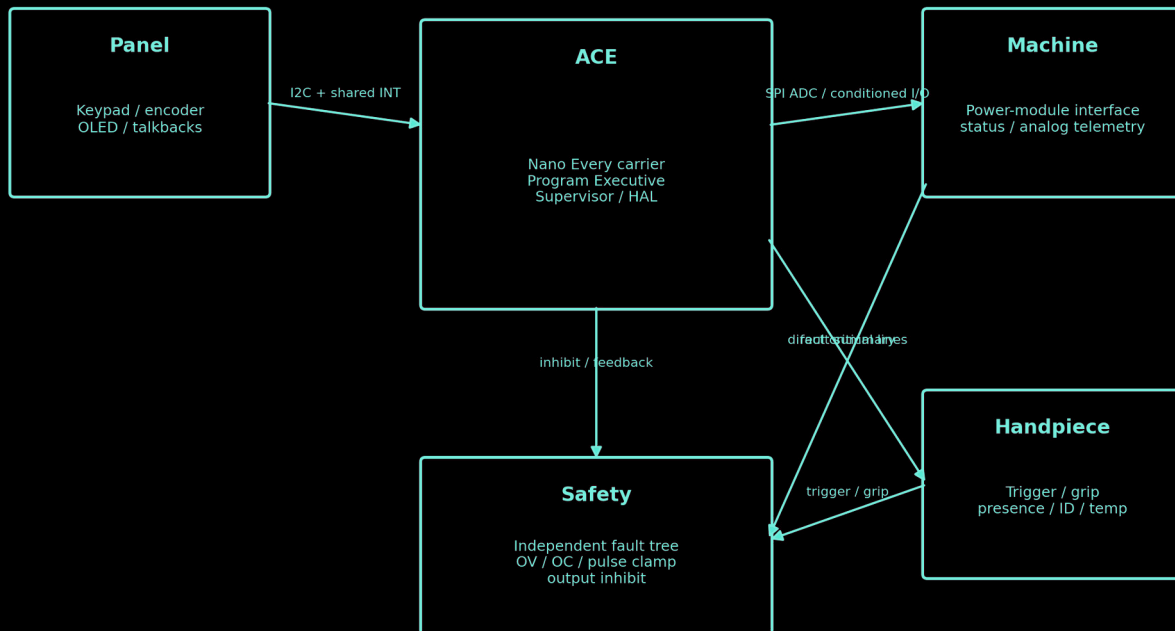
Included	Excluded / deferred
Executive, Program and Routine architecture	Energy-stage construction and component sizing
Program/Verb/Noun command grammar	Mechanical electrode geometry
Panel, display, alarm and restart semantics	Characterized pulse-energy limits
Direct pins, expanders, ADC and FRAM contracts	Final RevB/C production harness dimensions
Memory, timing, tests and firmware migration	Any software-only bypass of hardware safety

Frozen design axioms

1. The display is never part of authorization or critical timing.
2. Operator input is a request; the Safety Supervisor and hardware facts remain authoritative.
3. A Program is not a MachineState, and selecting a Program never implies authorization.
4. All outputs default inhibited after reset, brownout, watchdog expiry, invalid state or loss of required facts.
5. Critical signals use direct MCU or independent hardware paths; I2C expanders carry noncritical panel and machine I/O.
6. Profiles are typed data records in RevA, not executable bytecode.
7. Every queue, table, buffer, sequence and record has a fixed maximum.
8. No restart resumes an armed, active or partially completed action.
9. Program, Verb, Noun, Prompt and Alarm descriptors are immutable flash data.
10. Failure of advisory services can only preserve or reduce authorization.

2. System Partitioning and Ownership

ACE SYSTEM PARTITION AND SIGNAL OWNERSHIP



Hard-safe paths do not depend on I2C, OLED, panel expanders, or the cooperative executive.

Figure 2. ACE partition and conditioned interfaces.

Layer / service	Authority	Primary responsibility
Independent hardware safety	Highest	Inhibit defaults, trip comparators, maximum-window clamp, fault summary
Safety Supervisor	Safety state	MachineState, AuthorizationState, fault response and readiness predicates
Program Executive	Operational flow	Active Program, phase, entry/exit/fallback and Program requests
Routine Scheduler	Reusable work	One foreground Routine, bounded background services and ownership tokens
Command Executive	Operator grammar	V37 and Verb/Noun command construction, staging and validation
Display / Prompt / Alarm	Presentation	Display arbitration, response contracts, KEY REL and V05 N09
HAL / drivers	Hardware facts	Direct pins, expanders, ADC, FRAM and coherent snapshots
DESIGN NOTE: The old A/0.1 concept of one ARCEXEC object owning the state machine, scheduler, profile interpreter and panel is retired. The cooperative Executive remains the dispatcher, but authority is split among explicit owners.		

3. Orthogonal Runtime State Model

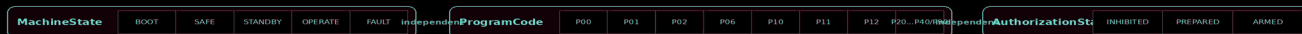


Figure 3. Independent runtime dimensions prevent Program identity from being confused with safety state.

Dimension	Owner	RevA values / rule
MachineState	Safety Supervisor	BOOT, SAFE, STANDBY, OPERATE, FAULT
ProgramCode	Program Executive	P00, P01, P02, P06, P10-P24, P30-P34, reserved service codes
AuthorizationState	Supervisor + hardware facts	INHIBITED, PREPARED, ARMED
ProgramPhase	Active Program	Program-specific bounded phase code
DisplayOwner	Display Executive	operator, monitor, Program, safety prompt, alarm detail
Output fact	HAL feedback	inactive/active; never inferred from Program or command state

Required invariants

- After successful startup the Supervisor enters SAFE while ProgramExecutive starts P00 SAFE IDLE.
- Program requests are rejected, accepted or deferred independently of MachineState transitions.
- Only the Supervisor may authorize SAFE/STANDBY/OPERATE/FAULT changes and INHIBITED/PREPARED/ARMED changes.
- Programs request preparation or operation; they never assign authorization directly.
- Any hard fault forces INHIBITED and FAULT or SAFE according to the fault policy, regardless of active Program.
- P00 remains a real active Program and is the fallback target for ordinary completion and cancellation.

DESIGN NOTE: `MachineState::program` and the transition `SAFE + PROGRAM\_REQUEST -> PROGRAM` are explicitly removed from RevA.

4. Executive Cycle and Event Architecture



Figure 4. Commands and hardware events travel through bounded validation and dispatch stages.

Current tested vertical slice

- `Event` remains a fixed 8-byte ABI record.
- `EventQueue` remains a fixed-capacity FIFO; overflow is reported and never overwrites an older event.
- `Executive::run\_once()` removes at most one event and returns IDLE, HANDLED or UNHANDLED.
- Host self-tests and the Nano Every PlatformIO build remain the development gate.

Revised dispatch order

Order	Consumer	Action
1	Layer-0 / critical capture	Immediate inhibit/cutoff facts and bounded ISR publication
2	Safety Supervisor	Evaluate faults, MachineState and AuthorizationState
3	Program Executive	Handle Program request, phase, completion and fallback events
4	Routine Scheduler	Release foreground/background work and enforce ownership
5	Command / Prompt / Display	Handle key grammar, prompts, display ownership and restoration
6	Storage / diagnostics	Run only within remaining budget and permitted state
DESIGN NOTE: No component is allowed to spin waiting for completion. Completion, timeout and cancellation are events. This keeps stack depth and latency bounded.		

5. Revised Memory and Resource Model

Resource	Frozen policy	Planning gate
48 KB flash	Native code, drivers, descriptor tables, strings and compact fonts	Warning near 38 KB; formal review near 42 KB
6 KB SRAM	Active state, queues, snapshots, page/tile display buffer and stack	Static allocation target below 3 KB; preserve at least 2 KB measured stack margin
256 B EEPROM	Board identity and boot-critical fallback only	No profiles, histories or high-cycle counters
External FRAM	Profiles, calibration, alarm/restart records, counters	Required MB85RC256V-class device at I2C 0x50
OLED buffer	Page/tile rendering preferred	128-256 B target; 1,024 B full buffer only after measured review
Descriptor tables	Immutable program flash	No SRAM copies of complete Program/Verb/Noun catalogues

RevA SRAM planning allocation

Allocation	Target	Notes
Supervisor, Program and command state	300-500 B	Includes one active Program and one interrupted DisplayContext
Event queues and Routine table	200-350 B	Fixed counts and compact records
Telemetry and sensor filters	400-750 B	No large sample histories
OLED page/tile buffer	128-256 B	Preferred renderer strategy
Wire/SPI/UART/library state	350-700 B	Must be measured from linked image
Formatting scratch	<=256 B	No large printf buffers
Stack and interrupt reserve	>=2,048 B	Release gate is measured high-water margin
DESIGN NOTE: ARCVm bytecode, its interpreter stack and active profile cache are removed from the RevA memory budget. Profiles are typed records; automatic flow uses fixed sequence descriptors.		

6. Timing, Interrupts and Critical Windows

Resource / source	Logical owner	Permitted work
Dedicated cutoff timer	Layer 0 timed-action service	Terminate request, latch completion and minimal bookkeeping
Control timebase	Executive / scheduler	Publish due events and monotonic time
Watchdog	Layer 0	Reset after missed service; hardware inhibit already dominant
Direct input interrupt	Critical input capture	Capture edge/state and publish bounded event
SPI ADC completion	Sensor service	Store sample/status; no formatting or policy
Expander interrupt	Panel/machine input service	Schedule bounded register read outside critical window

ISR policy

11. Perform only the immediate safety action or capture.
12. Publish a volatile flag, counter or fixed event.
13. Clear the interrupt source.
14. Return immediately.
15. Perform policy, command interpretation, display and logging in normal executive context.

Critical-window contract

- No OLED refresh, FRAM write, nonessential I2C transaction or serial formatting begins inside the timed window.
- The last valid display remains visible; direct talkbacks and inhibit hardware remain active.
- The timed-action service owns the output request and timer until completion or fault.
- The exact ATmega4809 peripheral assignment is frozen only after auditing ArduinoCore-megaAVR timer use; architectural ownership is already frozen.

7. HAL, Facts and Telemetry Snapshots

The Hardware Abstraction Layer is the only firmware layer that knows physical pins, bus addresses or ADC channels. Upper layers consume typed facts and submit typed requests.

HAL domain	Back-end	Examples
Critical digital	Direct Nano GPIO	FAULT_SUM, TRIP_OV, ARM_SW, HARD_SAFE_SW, GRIP_SW, TRIGGER_SW, OUTPUT_FB, TRIP_OC
Critical requests	Direct Nano GPIO	HW_INHIBIT, CHARGE_ENABLE, PULSE_CMD
Panel input/output	MCP23017 at 0x20 / 0x21	4 x 5 keypad, encoder, talkbacks, sounder, OLED reset
Machine noncritical I/O	MCP23017 at 0x22	charger ready/fault, fan, bleed, contact-test and service facts
Analog acquisition	SPI ADC on D10-D13	VBANK, currents, temperatures, rail health, contact test, tool ID
Persistence	I2C FRAM at 0x50	Profiles, calibration, alarms, restarts and counters

Fact contract

Field	Meaning
value	Scaled integer or compact enum/bitset
valid	Driver and range checks succeeded
fresh	Age remains inside the channel contract
timestamp / sequence	Supports coherent snapshots and stale-data detection
source	Direct, expander, ADC, derived or hardware-latched
quality / fault	Open, short, out-of-range, mismatch or bus unavailable
DESIGN NOTE: Display and Programs read a coherent `TelemetrySnapshot`. They do not independently poll hardware or mix values from different acquisition cycles.	

8. Program Executive

ProgramExecutive owns the active Program code and phase. It validates manual V37 requests and internal sequence requests without changing safety authority.

Responsibility	RevA rule
Default Program	P00 SAFE IDLE starts after successful boot/recovery
Entry validation	Program exists; MachineState and authorization are compatible; required hardware is available
Lifecycle	Explicit requested, started, phase-changed, completed, aborted and fallback events
Fallback	Ordinary completion/cancel returns to P00; faults enter P02 or remain faulted according to policy
Safety interaction	Programs request preparation/operation; Supervisor independently accepts or rejects
Restart	Active Program phase is invalidated; no automatic resume of an unfinished action

V37 Program selection

16. Operator enters `VERB 3 7 ENTR`.
17. CommandExecutive raises a Program-code prompt.
18. Operator enters two digits and `ENTR`.
19. ProgramExecutive validates the ProgramDescriptor and present compatibility.
20. On acceptance it posts `program\_started`; on rejection it asserts OPR ERR and retains the current Program.

ProgramDescriptor minimum fields

code, title, permitted MachineStates, required hardware facts, allowed Verb set, phase table, normal fallback, fault fallback, restart policy and workspace size.

DESIGN NOTE: There is no physical PROG key. The Program number remains a display register and operator-visible status field.

9. Routine Scheduler and Automatic Sequences

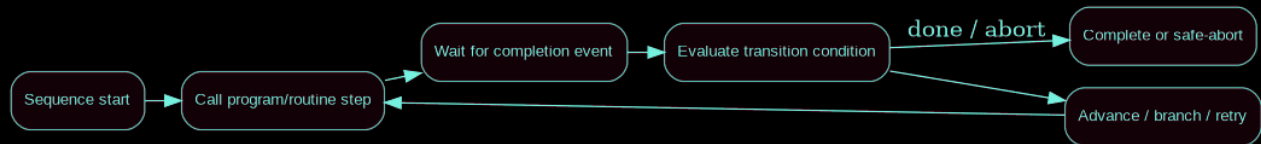


Figure 5. R07-style sequencing is a table of event-driven steps, not a bytecode interpreter or blocking call chain.

Class	Examples	Rule
Foreground Program	P10, P20, P31	Exactly one active major Program
Foreground Routine	contact test, preparation check, timed action	At most one Program-owned modal Routine
Background service	fact sample, display, panel, alarm	Bounded periodic/event-driven work
Exclusive hardware service	timed action, FRAM transaction	Ownership token prevents simultaneous use
Priority service	hardware cutoff, safety prompt	May preempt according to explicit policy

SequenceStep fields

Field	Purpose
request	Program or Routine request posted through normal event routing
completion_event	Expected successful event
timeout	Finite deadline and timeout event
condition / branch	Typed fact or result selects next step
abort_target	Safe Program/phase and cleanup request
progress code	Exposed through N02/N30 and stored in restart record
DESIGN NOTE: Every automatic transition must also be legal as a manual transition unless explicitly marked internal. Restart invalidates the active sequence and records the interrupted step.	

10. Command and Descriptor Architecture

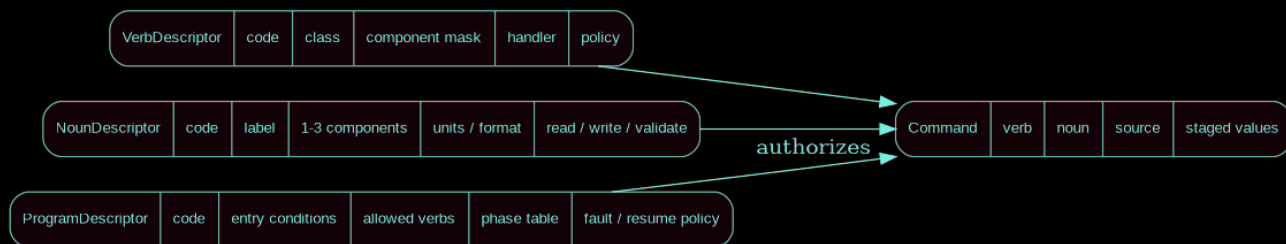


Figure 6. Immutable descriptors define command compatibility, formatting, validation and ownership.

Code type	Width / role
ProgramCode, RoutineCode, VerbCode, NounCode	Strong 8-bit wrapper; two-digit operator presentation
OptionCode, ChecklistCode, PromptCode, AlarmCode	16-bit typed codes with independent namespaces
ComponentValue	Fixed-width scaled integer plus validity and sign metadata
CommandBuilder	Staged Program/Verb/Noun fields and up to three components
DisplayContext	Owner, Program, Verb, Noun, mode and restoration metadata

Validation pipeline

21. Validate key sequence and field completeness.
22. Validate Verb and Noun existence.
23. Validate Verb/Noun component-mask compatibility.
24. Validate access mode, Program permission and MachineState permission.
25. Validate each staged component through its Noun component descriptor.
26. Commit atomically or reject the complete command; partial data never changes live state.

DESIGN NOTE: Program, Routine, Verb, Noun, Prompt and Alarm descriptor tables live in flash. Only current values and active contexts occupy SRAM.

11. Final Operator-Panel Contract



Figure 7. Frozen RevA operator panel. Program selection is V37; there is no PROG or ACK key.

Control	Meaning
VERB / NOUN	Select two-digit command fields
0-9, +, -	Enter numeric components and sign
CLR	Clear the staged field or cancel incomplete entry
ENTR	Commit a command/data word or answer an ENTR prompt
PRO	Proceed/approve the active Program prompt; not data entry
KEY REL	Relinquish an internal/monitor display and restore prior context
RSET	Clear eligible annunciation only after the underlying cause clears
Encoder + push	Browse lists and bounded edits; never replaces ENTR or PRO
ARM	Maintained physical authorization input
HARD SAFE / INHIBIT	Dominant physical removal of authorization

Talkbacks: SAFE, CHARGE, READY, ARMED, OUTPUT, FAULT, ENERGY and OPR ERR. They are physical status indications and are not inferred from the visible OLED page.

12. Display, KEY REL and Alarm Semantics



Figure 8. Display ownership preserves operator context while allowing required prompts and alarm detail.

Owner / class	Examples	KEY REL / exit behavior
Operator command	V/N entry, staged load	Cancel/release according to command state
Monitor	V11-V16 status page	Restore interrupted Program/operator display
Program prompt	load, review, proceed	Resolve only through descriptor-authorized ENTR, PRO, V32 or V34
Safety prompt	release trigger, set SAFE	Cannot bypass the required physical condition
Alarm detail	V05 N09 or P33 review	Return to prior nonblocking display
Blocking fault	required safe action	Cause remains authoritative even when detail page is released

Program alarm retrieval

- A normal Program alarm latches the FAULT/appropriate talkback and records its code without unnecessarily destroying the current display.
- `V05 N09` displays the first alarm after reset, the second alarm after reset and the latest alarm.
- `KEY REL` restores the interrupted display in ordinary nonblocking cases.
- `RSET` clears eligible annunciation only after the source condition is corrected; it does not erase the latest alarm record.
- There is no generic ACK key or ACK event in the final RevA panel contract.

DESIGN NOTE: RevA stores one interrupted DisplayContext. Nested display pressure is resolved by priority and pending-owner state rather than an unbounded stack.

13. Program, Routine and Profile Model

Range	Programs	Purpose
P00-P06	P00 Safe Idle, P01 Self-Test, P02 Recovery, P06 Standby	Executive and recovery
P10-P12	Single Operation, Repeat Session, Dry Run	Operational control and simulation
P20-P24	Profile Select/Edit, Material/Sensor Calibration, Tool Configuration	Configuration and characterization
P30-P34	System Status, Panel Test, I/O Diagnostics, Alarm/Restart, Storage Integrity	Monitoring and diagnostics
P40+	Restricted service / reserved development	Not part of ordinary operator flow

Routine model

Routines are short reusable services with explicit request, ownership, completion, timeout and abort contracts. They do not become Programs merely because they are reusable.

Profile model

- A RevA profile is a versioned typed record containing identity, material/tool choices, bounded parameters, repetition policy, validity and checksum.
- P20 selects/reviews profiles; P21 edits a working copy and validates it before atomic commit.
- P10 consumes a validated profile through native phase logic and Routine requests.
- No unrestricted profile instruction can write hardware, change safety limits or invoke an output directly.
- An interpreter or richer recipe language is deferred beyond RevA and must fit behind the same descriptor, Program and Supervisor contracts.

DESIGN NOTE: The A/0.1 ARCVm opcode set and bytecode ProfileRecord are removed from the RevA baseline.

14. Sensors, Switches and Machine I/O

Class	Connection	Representative signals
A - hard safety / timing	Direct GPIO or independent hardware	FAULT_SUM, TRIP_OV, TRIP_OC, ARM, HARD SAFE, GRIP, TRIGGER, OUTPUT_FB, HW_INHIBIT, PULSE_CMD
B - supervised control	Direct or machine expander	CHARGE_ENABLE, charger ready/fault, bleed, fan, enclosure and auxiliary interlocks
C - analog measurement	External SPI ADC	bank/input voltage, charge/output current, temperatures, logic rail, contact test, tool ID, reference monitor
D - panel / advisory	Panel expanders and local I2C	key matrix, encoder, talkbacks, buzzer, OLED reset

Frozen interface count

- Nano direct map uses D2-D13, A0-A7, A4/A5 I2C and TX/RX service UART under the master pin register.
- Three MCP23017 devices are required: panel input 0x20, panel output 0x21 and machine I/O 0x22.
- Analog acquisition is SPI: MCP3208 is acceptable for the RevA prototype; the HAL reserves sixteen channel identifiers for an ADS7953-class RevB/C device.
- External switches and analog signals enter through protection, filtering and conditioned interfaces. Raw high-energy conductors are outside ACE.
- I2C remains physically local; long/noisy harnesses use dedicated conditioned signals rather than remote raw I2C.

DESIGN NOTE: The panel expanders do not substitute for machine sensing. The complete controller budget includes the power module, handpiece, enclosure, fault latches and future characterization channels.

15. Fault, Inhibit, Restart and Recovery

Mechanism	Owner / path	Rule
Hardware inhibit	Independent path + A0 request	Dominant safe state; active at reset
FAULT_SUM	Direct D2 input	Immediate aggregate response; detailed cause may be read later
OV / OC trips	Direct comparator inputs	Independent thresholds cross-check telemetry
Fault-source latch	Machine interface	Preserves individual source bits for P33/V05 inspection
Alarm registers	AlarmManager + FRAM	First, second, latest and chronological records
Watchdog/reset record	Startup / P02	Reset cause and interrupted Program/phase recorded

Recovery rules

27. Assert hardware inhibit and force AuthorizationState to INHIBITED.
28. Capture fault source, reset reason, active Program, phase and relevant facts.
29. Enter FAULT or SAFE according to descriptor policy; do not resume the interrupted action.
30. Expose alarm codes through V05 N09 and the full record through P33.
31. Require the underlying condition to clear and any specified physical action to occur.
32. Use RSET only for eligible annunciation reset; enter P02 for structured recovery when required.
33. Return to P00 inhibited after successful recovery.

DESIGN NOTE: KEY REL can dismiss or restore display context; it never clears a fault, changes authorization or suppresses a hardware trip.

16. Persistent Storage and Record Integrity

Store	Permitted contents	Policy
Internal EEPROM	Board ID, schema selector, boot-critical fallback calibration	Rare writes only; compact CRC
External FRAM	Profiles, calibration, alarm/restart logs, usage/service counters	Primary mutable store; versioned and bounded
Program flash	Descriptors, defaults, immutable strings and lookup tables	Read-only during operation
SRAM	Working copies and current contexts	Lost on reset; never treated as authoritative history

Record header

Field	Purpose
type / version	Select parser and migration path
length	Bounds check before read
sequence	Chooses newest committed copy
flags	Validity, deleted, factory/default state
payload CRC	Detects corruption or partial update
commit marker	Makes two-slot or append update atomic

Required record groups

- profile directory and profile records;
- sensor and analog-channel calibration coefficients;
- first/second/latest alarm registers plus chronological alarm and restart log;
- usage counters, service history and configuration revision;
- last known safe shutdown metadata where it improves recovery diagnostics.

DESIGN NOTE: Firmware never assumes a stored layout from address alone. Every record is length- and version-checked before use; failure selects a safe default or P34 storage-integrity path.

17. Diagnostics, Simulation and Testability

Program / interface	Purpose	Output policy
P12 Dry Run	Exercise Program, Routine, prompt and display flows with synthetic facts	Physical output remains inhibited
P30 System Status	Read coherent machine and sensor facts	Read-only
P31 Panel Test	Exercise OLED, talkbacks, keypad, encoder and sounder	No machine output
P32 I/O Diagnostics	Inspect direct pins, expanders, ADC and bounded auxiliary tests	Critical outputs excluded or independently inhibited
P33 Alarm / Restart Review	Inspect codes, causes and interrupted context	Read-only except eligible record controls
P34 Storage Integrity	Verify record headers, CRCs and directory consistency	Atomic repair only in safe service state
Service UART	Build ID, structured test results, recovery diagnostics	Unavailable as an authorization channel

Required test families

- Host tests for queue overflow, event routing, state/Program independence and descriptor uniqueness.
- Command tests for every legal and illegal Verb/Noun/component combination.
- Display tests for preemption, KEY REL restoration and V05 N09 alarm semantics.
- Restart tests proving authorization always returns INHIBITED and sequences never resume.
- HAL simulator tests for stale, invalid, mismatched and absent sensor facts.
- Timing instrumentation for worst-case service latency, stack high-water mark and critical-window exclusion.
- Hardware-in-loop tests begin with sensor simulators and independent output inhibit asserted.

18. Coding Rules and Firmware Migration

Rule	Requirement
Allocation	No heap, recursion or unbounded containers after startup
Types	Fixed-width integers and strong code wrappers; no raw pin numbers above HAL
Tables	Compile-time counts, uniqueness checks and explicit maximums
Arithmetic	Scaled integer engineering units in critical/control paths
Libraries	Timer, SRAM, blocking and interrupt behavior audited before adoption
Errors	Rejected requests produce explicit result/alarm events; no silent fallback toward permissive behavior
Tests	Host and target builds share the same core state, Program and descriptor logic

Required migration from the current firmware

34. Rename/remove ``MachineState::program``; use ``operate`` and add ``ProgramCode active_program``.
35. Keep the fixed `Event/EventQueue/run_once()` vertical slice and add explicit event families.
36. Add `ProgramExecutive` with P00, P30 and host tests before operational Programs.
37. Add typed Verb/Noun descriptors and `CommandBuilder`, beginning with V01/V05/V16/V37 and N01/N02/N09.
38. Add `DisplayExecutive` with one interrupted `DisplayContext` and KEY REL tests.
39. Add `PromptManager` response contracts for ENTR, PRO, KEY REL and RSET only.
40. Add HAL back-ends for direct GPIO, three expanders, SPI ADC and FRAM.
41. Implement P12 simulation before binding P10 to any real timed-action interface.
42. Implement P10 as a native phase table plus Routine events; do not reintroduce ARCVm.
43. Measure final flash, static SRAM, stack, timers and service latency before RevA acceptance.

Appendix A. RevA Summary and Acceptance Gates

Area	Frozen RevA decision
Runtime authority	Supervisor, ProgramExecutive, RoutineScheduler, CommandExecutive, Display/Prompt/Alarm and HAL have separate ownership
Default execution	P00 active in SAFE after boot/recovery
Panel	4 x 5 matrix; PRO retained; PROG and ACK deleted; V37 selects Programs
Alarm interaction	V05 N09 = first/second/latest; KEY REL restores nonblocking context; RSET only after cause clears
Memory	Page/tile OLED buffer, immutable flash descriptors, typed profiles in FRAM, no ARCVM
Expansion	Three MCP23017, SPI ADC, I2C FRAM and local shared I2C bus
Critical I/O	Direct GPIO plus independent comparator/clamp/fault paths
Persistence	Versioned bounded records with integrity and atomic commit
Revision compatibility	RevB/C may change physical implementations behind the HAL but preserve codes, records and operator semantics

RevA acceptance gates

- All descriptor codes are unique and every writable Noun has a validator.
- Every Program has entry, normal fallback, fault fallback and restart policies.
- Every prompt has a terminating response and safe timeout/default.
- No test can reach ARMED or output-active from a display, expander or storage failure.
- Measured static SRAM remains below the approved gate and worst-case stack margin remains at least 2 KB.
- Timer ownership is audited against the actual Arduino core and libraries.
- Power-on, watchdog, brownout and fault-injection tests all assert inhibit before normal services.
- The master PDF, this A.1 manual, hardware register and PVN catalogue agree on panel keys, pin names, codes and record ownership.

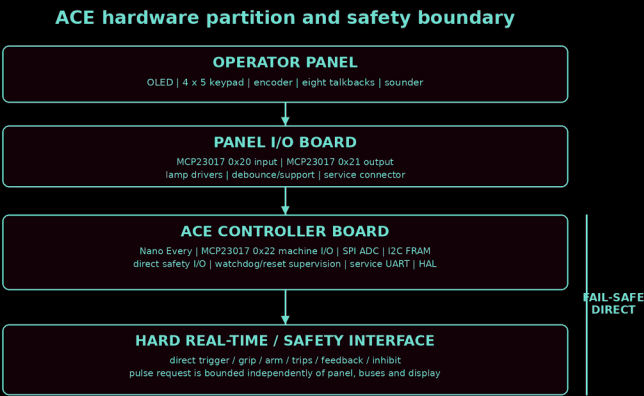
DESIGN NOTE: Revision A.1 is the corrective control-architecture baseline. The original A/0.1 memory map, ARCVM interpreter, rotary-menu-only HID and combined ARCEXEC authority are retained only as historical background in earlier files, not as normative design.

NANOARC

ACE Hardware and Operator-Panel Architecture Manual

Revision A.1 - Frozen Hardware, Panel and Pin Baseline

AGC-inspired low-voltage control hardware for the Arduino Nano Every platform



Field	Value
Document	NA-ACEHW-001
Revision	A.1 / Master Revision 1.2
Date	2026-06-26
Status	Frozen RevA hardware/interface baseline
Controller	Arduino Nano Every / ATmega4809 at 20 MHz

DESIGN NOTE: This manual defines the low-voltage ACE controller, operator panel and conditioned interfaces. It is not an energy-stage construction or operating procedure.

Document Control

Revision	Date	Status	Summary
A.0 / 0.1	2026-06-24	Superseded	Preliminary two-expander, direct-ADC, 4 x 4 keypad and seven-talkback hardware model.
A.1 / 1.0	2026-06-26	Frozen	Aligns the 20 MHz Nano Every, frozen direct pin map, three MCP23017 expanders, SPI ADC, I2C FRAM, 4 x 5 keypad and eight talkbacks with NA-MASTER-001 Revision 1.2.

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- 18. EMC and Noise Resilience
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- 21. Revision A Prototype Plan
- 22. RevA Component Baseline
- 23. Verification and Acceptance
- 24. Deferred Decisions
- Appendix A. Frozen Direct Pin Assignment
- Appendix B. I2C and SPI Registry
- Appendix C. Talkback Behaviour
- Appendix D. Connector Register
- References

DESIGN NOTE: This A.1 issue is firmware-facing and normative. The superseded A.0 pin, keypad, expander and sensor allocations must not be used in new code.

1. Purpose and Scope

This manual defines the physical architecture of ACE - the Arc Control Executive hardware and its human interface. It covers the Nano Every carrier, operator panel, low-voltage power domains, direct safety and real-time signals, serial buses, panel expansion, connectors, diagnostics and Revision A prototyping strategy.

The purpose is to let the control module mature while the energy-stage hardware is still being funded and developed. The ACE controller can therefore be assembled, programmed, exercised and verified against sensor simulators and low-energy fixtures before it is connected to any output stage.

- The document is authoritative for ACE hardware partitioning and interface ownership.
- The control-system and HID architecture manual remains authoritative for software behaviour.
- Energy storage, discharge switching and electrode construction are outside this manual.
- No panel bus or display function is permitted to become a single point of failure for hard inhibit or pulse termination.

2. Design Basis and Status

ACE uses static resources, explicit ownership, bounded interfaces and a strong separation between convenience functions and the hard safety path. RevA is frozen at the interface level; only the electrical values specifically marked deferred remain open.

Design driver	Frozen consequence
Nano Every resource limits	Use three GPIO expanders, an external SPI ADC and external FRAM.
6 KB SRAM	Use page/tile OLED rendering and flash-resident descriptors.
Shared I2C fault domain	Keep I2C local, use one pull-up network, bounded timeouts and recovery.
Hard safety boundary	Keep trips, physical controls, inhibit, pulse request and output feedback direct.
Complete sensor/switch census	Provide a machine-I/O expander and conditioned handpiece/power-module interfaces.
Firmware determinism	Freeze pin names, addresses, signal polarity and safe reset defaults.
Field serviceability	Use keyed connectors, test points, board IDs and replaceable subassemblies.

DESIGN NOTE: A.1 supersedes all A.0 phrases such as “preliminary pin budget,” “two expanders,” “4 x 4 keypad,” “seven talkbacks,” and “direct analog channels.”

3. ACE Hardware Boundary

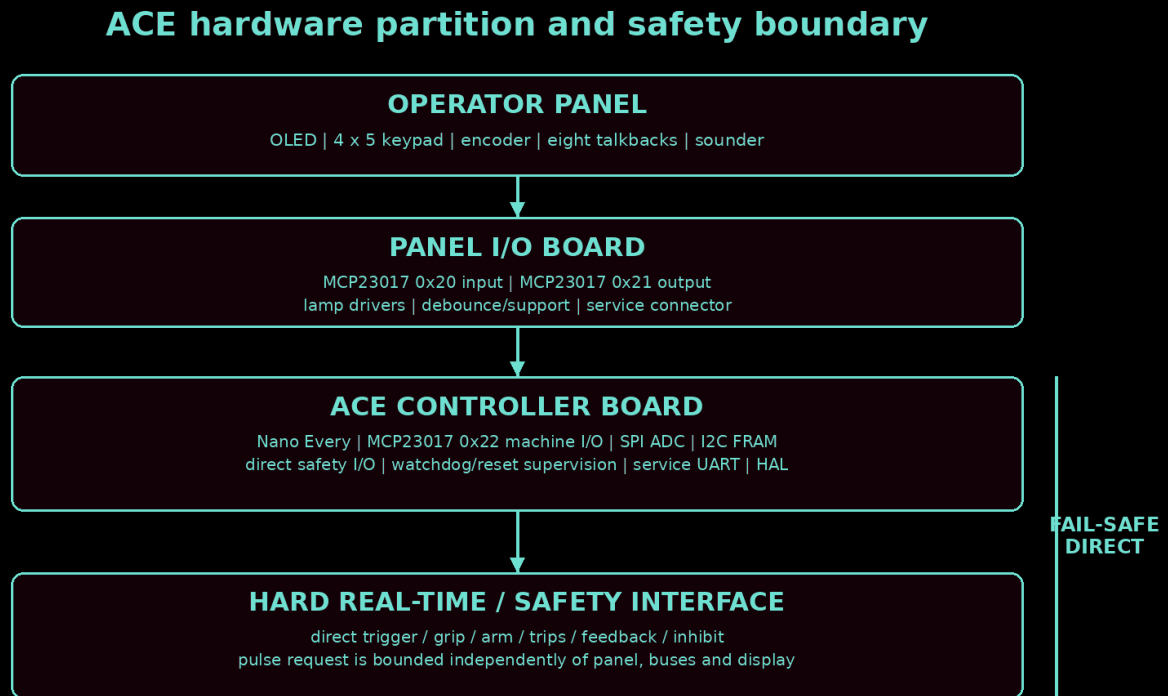


Figure 2. Hardware layers from operator panel to direct safety interface.

ACE begins at the regulated low-voltage control-power entry and ends at clearly defined command, feedback and inhibit interfaces to the rest of NanoArc. It does not own the energy path itself. The controller may request charging or a timed pulse, but independent hardware must retain authority to block or terminate unsafe action.

3.1 Included hardware

- Nano Every carrier and local support circuitry
- Panel input and output expansion
- OLED, keypad, encoder, talkbacks and sounder
- Sensor and status interfaces
- Direct trigger, grip, arm, inhibit and fault signals
- Programming, service serial and diagnostic test points

3.2 Excluded hardware

- Energy-storage bank
- High-current switching network
- Charge-converter power stage
- Electrode and work-current path
- Mains-connected supply internals

4. Target Controller Platform

The frozen RevA controller is the Arduino Nano Every using the ATmega4809 at the board's 20 MHz clock. ACE treats the Nano as a replaceable processing module mounted on a carrier rather than as the complete controller.

Property	Baseline use in ACE
Processor	ATmega4809 AVR at 20 MHz.
Program memory	Firmware, immutable descriptors, diagnostics and constant strings.
SRAM	Executive state, fixed queues, snapshots, display page/tile buffer and stack.
Internal EEPROM	Board identity and boot-critical fallback only; no profiles or logs.
I2C/TWI	Three MCP23017 expanders, OLED, FRAM and registered local devices.
SPI	External ADC on D10-D13.
UART	Service, recovery and development diagnostics.
Timers / RTC-PIT	Bounded output-window request and cooperative executive timing.
Internal ADC	Reserved for contingency or board-local checks; not the primary sensor census.

4.1 Carrier-board policy

- Socket or header-mount the Nano Every for replacement.
- Expose every direct Class-A signal and bus at a labelled test point.
- Do not route high-current paths under or through the controller carrier.
- Preserve USB/programming access after installation.
- Treat the Section 8 pin map as configuration-controlled firmware ABI.
- Do not repurpose a frozen pin without a master-baseline revision.

5. Hardware Partitioning

The control module is divided into replaceable functional assemblies. Breakout modules are acceptable in RevA, but their logical boundaries must match the final PCB architecture.

Assembly	Primary contents	Failure containment
ACE carrier	Nano Every, FRAM, reset/watchdog, bus pull-ups, direct-I/O conditioning	Owns processing and direct Class-A interfaces.
Panel I/O board	MCP23017 at 0x20 and 0x21, lamp drivers, keypad/encoder connectors	Panel failure cannot authorize machine outputs.
Machine I/O / analog board	MCP23017 at 0x22, SPI ADC, analog front end, comparator/fault latch	Contains slow machine facts and measurement acquisition.
Operator panel	OLED, 4 x 5 keypad, encoder, eight talkbacks, sounder, hard controls	Replaceable mechanical interface.
Conditioned harness interface	Handpiece, power-module and enclosure connector protection/filtering	Keeps remote/noisy wiring away from the MCU carrier.

DESIGN NOTE: A second microcontroller is not part of RevA. Expansion devices report or drive bounded I/O; command and authorization authority remains in ACE and independent hardware.

6. Power Distribution and Reset

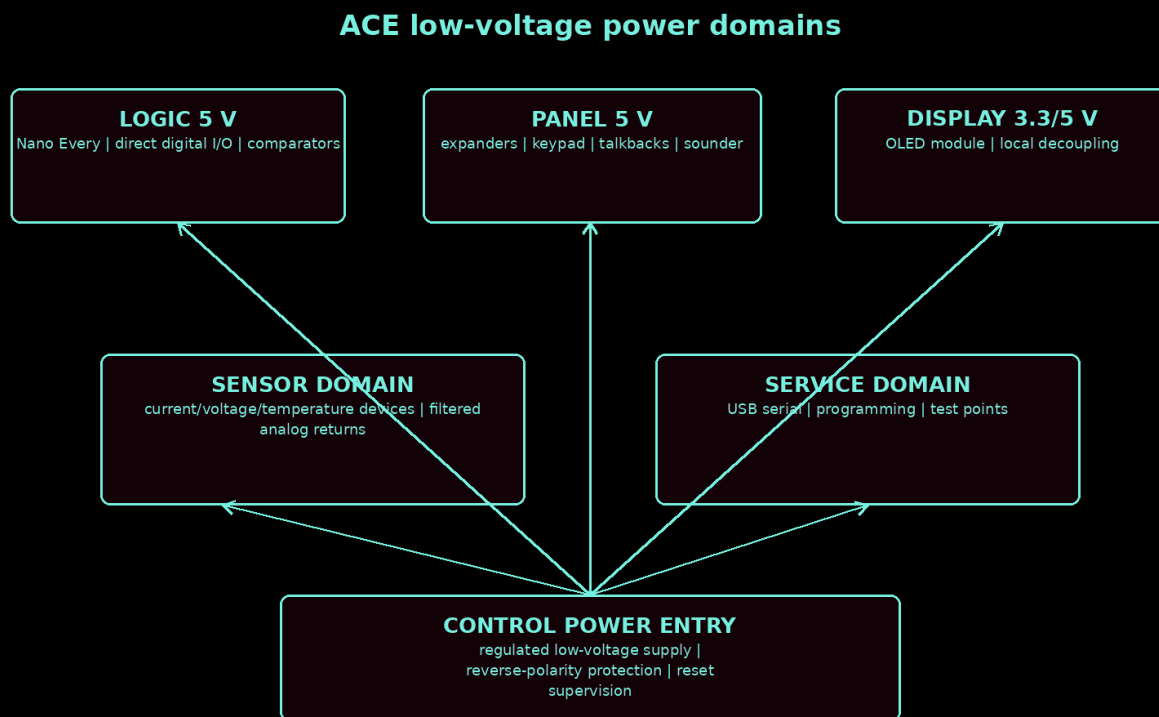


Figure 3. Proposed low-voltage ACE power domains.

ACE should receive a regulated low-voltage supply from the broader NanoArc power system. The controller carrier then distributes logic, panel, display and sensor power through locally protected branches. This avoids placing every accessory directly on the Nano Every 5 V header.

6.1 Required functions

- Reverse-polarity protection at control-power entry
- Bulk and local decoupling
- Reset supervision or brownout-aware startup
- Separate branch protection or current limiting for panel and external sensors
- Test points for each rail and ground
- Documented current budget with at least 25 percent growth margin

6.2 Reset behaviour

Any reset must leave the external inhibit asserted. Panel lamps may momentarily blank, but hardware FAULT and ENERGY indication should remain capable of asserting independently. ACE does not infer SAFE merely because the MCU has restarted.

7. Signal Classification and Ownership

Class	Examples	Routing rule
A - hard safety / timing	trips, arm, hard-safe, grip, trigger, output feedback, inhibit, pulse request	Direct Nano pin and/or independent hardware path.
B - supervised machine I/O	charger ready/fault, bleed confirm/enable, fan, auxiliary interlock	Machine expander unless consequence or latency requires direct routing.
C - analog measurement	voltage, current, temperatures, contact test, tool ID, reference monitor	Conditioned external SPI ADC channel with validity and stale-data checks.
D - human interface	keypad, encoder, talkbacks, sounder, OLED reset	Panel expanders and local I2C.
Storage / service	FRAM, build ID, UART diagnostics	Bounded service interfaces; never authorize output.

Signal class determines implementation. No Class-A action may depend solely on I2C, the OLED, a profile record or a displayed prompt.

8. Frozen Nano Every Pin Map

Frozen Nano Every direct pin map - RevA

PIN	SIGNAL	DIR	OWNER / NOTE
D2	FAULT_SUM	IN	direct aggregate fault
D3	TRIP_OV	IN	independent overvoltage trip
D4	ARM_SW	IN	maintained physical authorization
D5	HARD_SAFE_SW	IN	dominant physical safe control
D6	GRIP_SW	IN	handpiece enabling contact
D7	TRIGGER_SW	IN	final operator request
D8	OUTPUT_FB	IN	command/actual cross-check
D9	PULSE_CMD	OUT	timer-owned request
D10	ADC_CS	OUT	SPI ADC chip select
D11	SPI_MOSI	OUT	external ADC
D12	SPI_MISO	IN	external ADC
D13	SPI_SCK	OUT	external ADC
A0	HW_INHIBIT	OUT	default-safe hardware inhibit request
A1	CHARGE_ENABLE	OUT	supervised preparation request
A2	ENCLOSURE_INTLK	IN	direct enclosure/service interlock
A3	EXPANDER_INT	IN	shared open-drain input-expander IRQ
A4	I2C_SDA	BUS	expanders, OLED, FRAM
A5	I2C_SCL	BUS	expanders, OLED, FRAM
A6	HANDPIECE_PRESENT	IN	direct presence indication
A7	TRIP_OC	IN	independent current-trip comparator
AREF	RESERVED	-	reference or emergency reserve
TX/RX	SERVICE_UART	BUS	build, test and recovery diagnostics

Figure 4. Frozen direct-pin assignment. The names are firmware ABI, not examples.

The direct margin is intentionally exhausted by Class-A signals, SPI, I2C and service access. Slow machine I/O and analog channels are externalized so the direct safety path remains deterministic.

8.1 Allocation policy

- D2-D9 and A0-A2/A6/A7 are owned by named direct signals.
- D10-D13 are the external ADC SPI interface.
- A3 is the shared open-drain interrupt from input-capable expanders.
- A4/A5 are the local I2C bus.
- TX/RX remain the service UART.
- AREF remains reserved.
- Firmware must use symbolic names from the pin registry; numeric literals outside the HAL are prohibited.

9. Serial Buses and Address Registry

ACE local buses and fixed device ownership

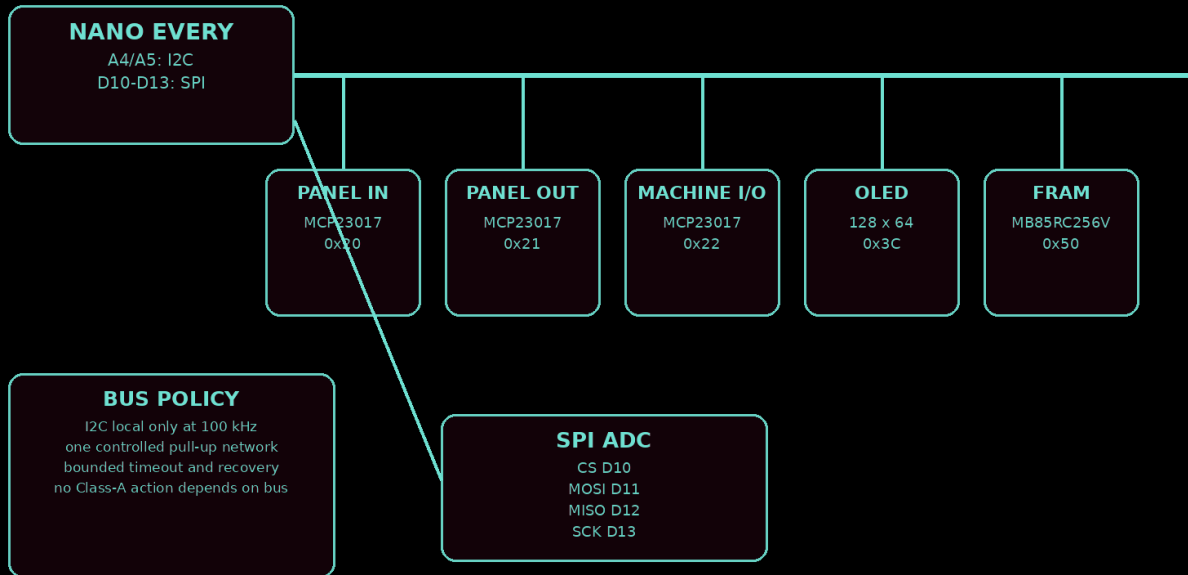


Figure 5. Local I2C ownership and separate SPI analog acquisition.

9.1 Frozen address plan

Address / interface	Owner	Status
I2C 0x20	Panel-input MCP23017	required
I2C 0x21	Panel-output MCP23017	required
I2C 0x22	Machine-I/O MCP23017	required
I2C 0x3C	128 x 64 OLED	required; module controller verified at procurement
I2C 0x40-0x47	Registered local machine sensor/control targets	reserved
I2C 0x50	MB85RC256V-class FRAM	required
I2C 0x68	Optional RTC	DNP in RevA unless justified
SPI D10-D13	External ADC	required

9.2 Bus rules

- RevA I2C begins at 100 kHz.
- One controlled pull-up network is fitted on the ACE carrier; daughterboard pull-ups are DNP by default.
- Every transaction has a finite timeout and explicit error result.
- Required addresses are checked individually; a bus scanner is service tooling, not boot policy.
- A bounded recovery attempt precedes a bus-failed fact.
- Raw I2C does not leave the local ACE/panel enclosure.
- Analog acquisition remains on SPI and is represented through a coherent TelemetrySnapshot.

10. Operator Panel Hardware



Figure 6. Frozen operator panel. Program selection uses V37; there is no PROG or ACK key.

Element	Purpose
128 x 64 OLED	Program/Verb/Noun header, logical R1-R3 data, prompts, monitors and alarm detail.
4 x 5 keypad	Verb/Noun entry, digits, sign, CLR, PRO, ENTR, KEY REL and RSET.
Rotary encoder	Browsing and bounded editing; push is local selection only.
Eight talkbacks	SAFE, CHARGE, READY, ARMED, OUTPUT, FAULT, ENERGY and OPR ERR.
Piezo sounder	Acceptance, rejection and attention patterns.
ARM switch	Mechanically distinct maintained direct input.
HARD SAFE / INHIBIT	Dominant physical safe control and direct input.

10.1 Human-factors goals

- Readable at bench distance and usable with one hand.
- No dependence on colour alone.
- Distinct tactile form for ARM and HARD SAFE.
- No generic acknowledgement key or overloaded program-selection key.
- Critical talkbacks remain visible regardless of OLED ownership.

11. Keypad and Encoder

11.1 Keypad baseline

Row	C0	C1	C2	C3	C4
R0	VERB	NOUN	+	-	CLR
R1	7	8	9	KEY REL	RSET
R2	4	5	6	PRO	ENTR
R3	1	2	3	0	SPARE

The 4 x 5 matrix consumes nine expander lines and has nineteen functional keys plus one reserved position. RevA rejects rollover and impossible combinations; per-key diodes are deferred unless testing requires them.

Program selection is the physical sequence VERB 3 7 ENTR, two Program digits, ENTR (V37E##E).

11.2 Encoder baseline

- Quadrature A/B input plus momentary push.
- Detent-based browsing and bounded adjustment.
- Encoder push selects a local field; it never substitutes for ENTR or PRO.
- Acceleration is optional and may not skip validation or final-value presentation.
- Encoder events are advisory human-interface events, not authorization facts.

12. Talkbacks and Audible Indication

Talkback	Authoritative meaning	Default after reset
SAFE	Hardware and software inhibits are verified asserted.	off until verified
CHARGE	Preparation/charging request is active and confirmed as applicable.	off
READY	Current Program readiness conditions are satisfied.	off
ARMED	Physical authorization has been accepted by the Supervisor.	off
OUTPUT	Output-active feedback is present.	off
FAULT	A blocking hardware or ACE fault is active.	hardware may force on
ENERGY	Stored-energy or equivalent hazardous-condition fact is present.	hardware may force on
OPR ERR	The most recent operator sequence was invalid or rejected.	off

FAULT and ENERGY should have a hardware override or independent local indication where practical. OPR ERR belongs to command/panel error handling, not to generic alarm acknowledgement.

12.1 Sound patterns

Pattern	Meaning
short click	key accepted
double chirp	command or Program request accepted
low short tone	key sequence or command rejected
repeating attention tone	fault or required physical action needs attention
continuous tone	not used in RevA

13. GPIO Expansion

RevA GPIO expansion allocation

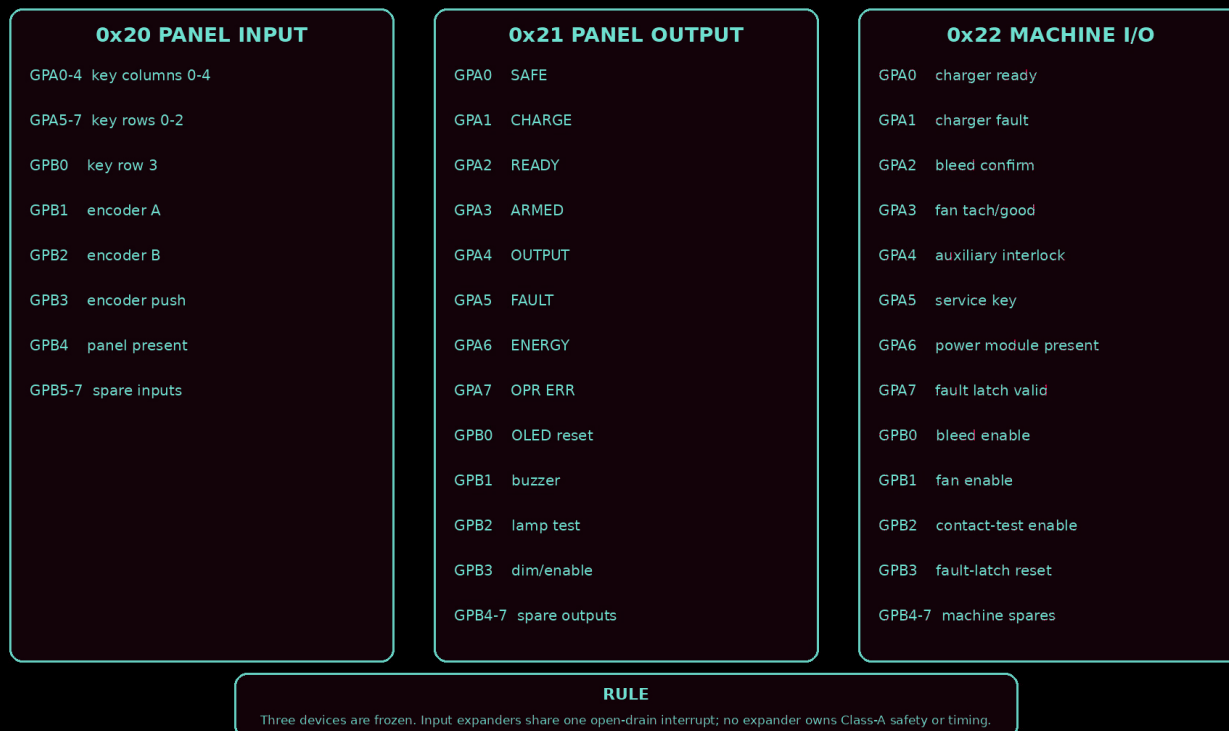


Figure 7. Frozen allocation of the three MCP23017 devices.

13.1 Panel-input expander - 0x20

- GPA0-GPA4: key columns 0-4.
- GPA5-GPA7 and GPB0: key rows 0-3.
- GPB1/GPB2/GPB3: encoder A/B/push.
- GPB4: panel-present.
- GPB5-GPB7: spare inputs.

13.2 Panel-output expander - 0x21

- GPA0-GPA7: eight talkbacks in the frozen order SAFE through OPR ERR.
- GPB0: OLED reset.
- GPB1: buzzer.
- GPB2: lamp test.
- GPB3: panel dim/enable.
- GPB4-GPB7: spare outputs.

13.3 Machine-I/O expander - 0x22

Inputs: charger ready/fault, bleed confirmation, fan tach/good, auxiliary interlock, service key, power-module present and fault-latch valid.

Outputs: bleed enable, fan enable, contact-test enable and fault-latch reset, plus four revision spares.

The input-capable expanders share A3 through open-drain interrupt outputs. Firmware always reads the interrupt-capture/status registers to identify the source.

13.4 Driver stage

A transistor array or qualified discrete stage isolates the output expander from lamp and sounder current. Reset/default hardware must keep all machine outputs inactive even though MCP23017 pins power up as inputs.

14. Direct Safety and Real-Time Inputs

The following signals bypass GPIO expanders. Their electrical defaults indicate safe/unavailable when wiring is open or the MCU is reset.

Signal	Direction	Required property
FAULT_SUM	input	aggregate open-drain critical fault; immediate inhibit response
TRIP_OV	input	independent overvoltage comparator
TRIP_OC	input	independent current-trip comparator
ARM_SW	input	maintained physical authorization
HARD_SAFE_SW	input	dominant physical safe control
GRIP_SW	input	independent handpiece enabling contact
TRIGGER_SW	input	final operator request; safe on open
ENCLOSURE_INTLK	input	direct enclosure/service interlock
HANDPIECE_PRESENT	input	direct presence fact
OUTPUT_FB	input	commanded-versus-observed cross-check
PULSE_CMD	output	timer-owned bounded request; hardware-limited downstream
CHARGE_ENABLE	output	inactive on reset
HW_INHIBIT	output	asserted/dominant safe on reset

Trigger acceptance is a system decision, never a single pin read. Required facts include compatible MachineState, physical controls, valid hardware facts, no blocking fault and independent inhibit availability.

15. Display Hardware and Memory Impact

The baseline display is a physically larger 128 x 64 monochrome OLED module using an SSD1306-class controller. A larger panel improves readability without increasing the pixel count or command model.

15.1 Buffer strategy

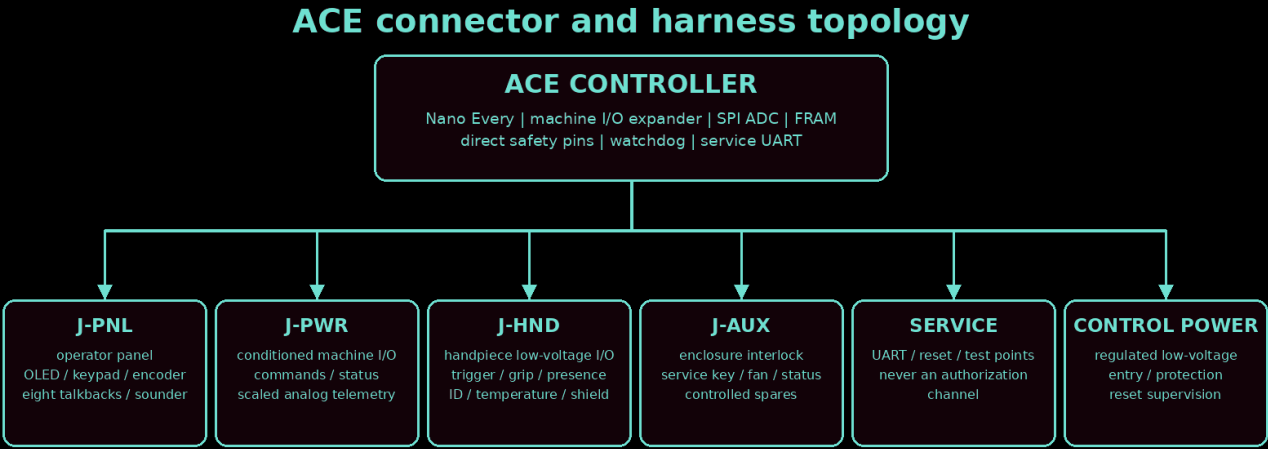
A full monochrome framebuffer requires 1,024 bytes, which is a significant fraction of the Nano Every 6 KB SRAM. ACE should therefore support a page-buffered or streamed renderer unless measurement proves that a full buffer still leaves adequate worst-case stack and runtime margin.

Mode	SRAM cost	Trade-off
Full framebuffer	1,024 bytes plus library state	simplest drawing, largest fixed SRAM cost
8-row page buffer	128 bytes plus renderer state	multiple passes, strong SRAM margin
Direct text/tiles	small fixed buffers	limited graphics but highly deterministic

15.2 Display failure behaviour

- OLED absence does not block SAFE operation or diagnostics over service serial.
- The system cannot arm through a display-only prompt; physical controls and talkbacks remain authoritative.
- A display fault raises a service or operator alarm according to machine state.
- The panel remains usable for hard-safe and arm-state reporting even if OLED initialization fails.

16. Connector and Harness Architecture



Connector policy

- J-PNL carries only local panel power, I2C and shared interrupt.
- J-PWR carries conditioned low-voltage machine commands/status and scaled telemetry.
- J-HND carries low-voltage sense/control only; high-current conductors use a separate connector.
- SERVICE is diagnostic only and cannot authorize operation.
- Raw energy-stage nodes never enter ACE or panel harnesses.

Figure 8. ACE board and harness partition.

Connector	Signals	Policy
J-PNL	local power, ground, SDA, SCL, shared IRQ, optional reset/service	keyed panel harness inside low-voltage enclosure
J-PWR	conditioned machine commands/status only	raw energy-stage nodes prohibited
J-HND	trigger, grip, presence, analog ID, temperature, shield/drain and returns	high-current conductors use a separate connector
J-AUX	enclosure interlock, service key, auxiliary fan/status and spares	low-voltage service functions only
SERVICE	UART, reset and test points	accessible without entering hazardous sections

16.1 Harness rules

- Condition and protect every external line at its connector entry.
- Keep shield/chassis termination distinct from analog and logic returns until the defined bond point.
- Pair remote digital signals with their return and separate noisy loads from analog returns.
- Do not carry raw I2C down the handpiece or into the power stage.
- Label both ends, identify pin 1 and provide strain relief.
- Connector pin meanings are configuration-controlled across revisions.

17. PCB and Daughterboard Strategy

The final ACE hardware should be implemented as a small stack or adjacent board set rather than one monolithic board. This keeps the Nano module replaceable and lets the operator panel evolve without touching the direct safety interface.

Board	Revision A implementation	Later implementation
Controller carrier	perfboard or prototype carrier with headers	dedicated PCB with Nano socket and direct-I/O conditioning
Panel I/O	breakout expanders plus driver board	single daughterboard behind front panel
Panel face	3D-printed or machined mockup	finished labelled faceplate and key legend
Sensor interface	terminal blocks and filter prototypes	dedicated filtered interface board

17.1 Mechanical constraints

- Keep the controller in the low-voltage compartment.
- Provide airflow without drawing conductive debris across boards.
- Orient the USB connector for service access.
- Keep the OLED and keypad replaceable from the front panel.
- Use standoffs and insulating barriers; do not rely on adhesive mounting alone.

18. EMC and Noise Resilience

NanoArc will contain fast current transitions elsewhere in the enclosure. ACE must therefore be designed as a noise-resilient control system even though it operates at low voltage.

- Keep direct safety and sensor wiring physically separated from high-current conductors.
- Use local decoupling at every IC and at each board connector.
- Filter analog channels at the receiving board and validate plausibility in firmware.
- Prefer Schmitt-trigger or comparator conditioning for long digital inputs.
- Use defined pull-ups or pull-downs so disconnected wiring fails predictably.
- Route I2C as a compact bus, not a star of long panel and sensor branches.
- Latch and report resets, brownouts and watchdog events.
- Verify that talkback or sounder switching does not disturb analog readings.

DESIGN NOTE: The Revision A control-module test plan should include deliberately noisy switching loads and cable movement before ACE is connected to the actual energy stage.

19. Startup Self-Test and Hardware Diagnostics

Deterministic power-on validation with inhibit held



Figure 9. Deterministic power-on validation with inhibit held.

19.1 Power-on checks

1. Assert/confirm HW_INHIBIT before peripheral initialization.
2. Capture reset reason and supply status.
3. Verify direct trips, controls and interlocks are electrically plausible.
4. Initialize fixed queues, Supervisor, ProgramExecutive and P01 state.
5. Recover and test the I2C bus.
6. Check MCP23017 devices at 0x20/0x21/0x22, OLED at 0x3C and FRAM at 0x50.
7. Initialize the SPI ADC and validate reference/known channels.
8. Verify stored record schema before any profile is exposed.
9. Exercise a bounded lamp test only when safe.
10. Post BOOT_COMPLETE only after mandatory checks pass; otherwise raise a typed alarm and remain inhibited.

19.2 Diagnostic observability

- Service UART reports reset cause, missing devices, direct facts and record-schema results.
- Test points expose buses, reset, inhibit, trips and rails.
- P31/P32 test panel and I/O without enabling Class-A outputs.
- Fault history distinguishes absence, invalid range, stale data, communication timeout and hardware trip.

20. Serviceability and Revision Management

- Assign board IDs and revision marks to controller, panel and machine-I/O boards.
- Store expected hardware identity and record schema in immutable firmware descriptors.
- Use FRAM for mutable profiles/logs; internal EEPROM is not a profile store.
- Do not silently repurpose a pin, address, connector contact, Noun or record ID.
- Firmware compatibility is declared against NA-MASTER-001 revision and board IDs.
- Service mode requires explicit policy and cannot bypass hard-safe hardware.

20.1 Recommended labels

Label	Example
Controller board	ACE-CTRL-A1
Panel I/O board	ACE-PANEL-A1
Machine I/O board	ACE-MIO-A1
Harness	ACE-HARNESS-P1
Firmware compatibility	ACE FW RevA / Master 1.2
Document	NA-ACEHW-001 A.1

21. Revision A Prototype Plan

Revision A control-module development stack

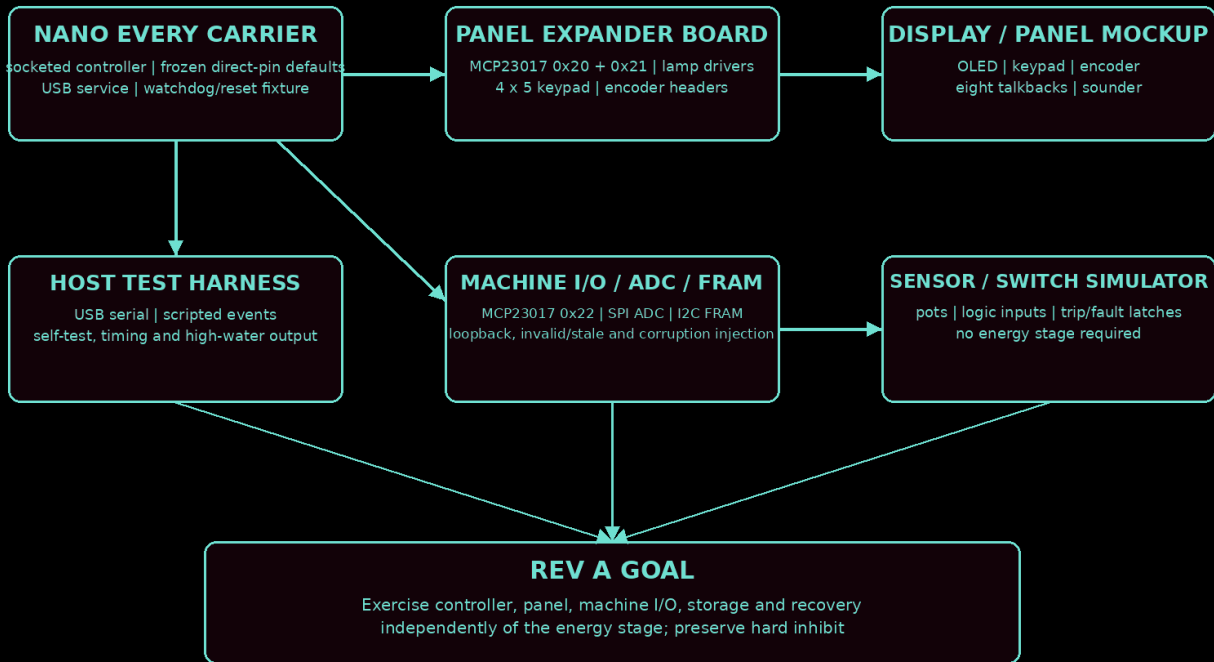


Figure 10. Standalone RevA control-module development arrangement.

21.1 Prototype stages

1. Nano Every carrier with frozen direct-pin safe defaults and service UART.
2. Panel-input and panel-output expanders with 4 x 5 keypad, encoder and eight talkbacks.
3. Machine-I/O expander loopback fixture.
4. OLED and page/tile renderer.
5. FRAM record layer and corruption/power-loss tests.
6. SPI ADC with sensor simulator and stale/invalid channel injection.
7. Fault-summary, trip and source-latch logic-level fixture.
8. Startup, recovery, bus-failure and watchdog tests.
9. Enclosure/harness mockup and noise testing.
10. Only after acceptance, bind to separately verified conditioned external interfaces.

21.2 Exit criteria

- Every keypad/encoder action is detected without phantom events.
- All eight talkbacks and sounder channels pass P31.
- Three expanders, OLED, FRAM and ADC recover or fail safe under injected faults.
- Every direct Class-A input dominates panel requests.
- Resets always return inhibited and never resume an unfinished action.
- Pin, address, connector and record registries match firmware constants.
- Host tests and Nano Every builds pass resource gates.

22. RevA Component Baseline

Item / family	Qty	Role	Status
Arduino Nano Every ABX00028	1	controller module	frozen
MCP23017	3	panel input, panel output, machine I/O	frozen
MB85RC256V-class FRAM	1	profiles, calibration, alarms, counters	frozen
MCP3208	1	RevA 8-channel SPI ADC	frozen prototype choice
ADS7953-class ADC	DNP RevA	RevB/C 16-channel migration target	interface reserved
precision ADC reference	1	analog reference and monitor	frozen family
comparator devices	as required	OV/OC/threshold trips	frozen function
SN74HC221-class monostable	1	independent maximum request window	frozen function
fault-source latch	1	post-event cause bitmap	frozen function
ULN2803A-class driver	1	eight talkbacks / sounder drive	frozen family
128 x 64 OLED	1	operator display	controller variant verified at procurement
4 x 5 key switches	19 + 1 spare position	command entry	frozen layout
EC11/PEC11-class encoder	1	browse and bounded edit	frozen function
talkback windows / LEDs	8	authoritative panel state	frozen count
ARM and HARD SAFE controls	1 each	direct physical controls	frozen function
connectors, ESD and filters	set	conditioned harness interfaces	values at schematic stage

The complete preferred part families and package choices are controlled by NA-MASTER-001 Section 23.

23. Verification and Acceptance

Test group	Minimum evidence
Power/reset	measured rails, reset causes and safe defaults
Direct Class-A I/O	open/closed/short simulation, trip response and polarity
Panel input	all 19 keys, spare position, encoder, debounce and invalid-combination rejection
Panel output	eight talkbacks, sounder, OLED reset and default-off behavior
Machine I/O	0x22 input/output loopback and interrupt-source handling
I2C	required-address checks, timeout, stuck-bus recovery and safe failure
SPI ADC	channel registry, reference check, invalid/stale/range behavior
FRAM	schema/version/CRC handling, corruption and interrupted-write behavior
Firmware integration	P01/P02/P31/P32/P34, fixed queues and resource gates
EMC/noise	switching-load, cable movement and false-trigger tests
Serviceability	keying, labels, test points and board replacement

23.1 Acceptance records

- Firmware commit/build hash and NA-MASTER revision.
- Board/harness IDs and populated options.
- Pin, address, ADC-channel, connector and storage-schema registries.
- Static SRAM, measured stack, queue high-water and timer ownership.
- Fault-injection and restart results.
- Known deviations and approved waivers.

24. Deferred Decisions

Decision	Frozen interface	Evidence still required
Final OLED vendor/controller	128 x 64 I2C at registered address	module electrical and viewing test
Production ADC population	SPI and 16 logical channel IDs	RevB noise/range characterization
Analog scaling	named channels and validity model	actual sensor transfer functions
Fault thresholds / clamp duration	independent trip and maximum-window interfaces	characterized machine requirements
Connector shell/keying variant	J-PNL/J-PWR/J-HND/J-AUX signal contracts	enclosure and availability review
Optional RTC/isolation	reserved address/population	demonstrated requirement

The keypad, talkback count, expander count, direct pin map, FRAM technology and program-selection controls are **not** open decisions.

Appendix A. Frozen Direct Pin Assignment

Pin	Signal	Direction	Ownership / note
D2	FAULT_SUM	input	direct aggregate critical fault
D3	TRIP_OV	input	independent overvoltage comparator
D4	ARM_SW	input	maintained physical authorization
D5	HARD_SAFE_SW	input	dominant physical safe control
D6	GRIP_SW	input	handpiece enabling contact
D7	TRIGGER_SW	input	final operator request
D8	OUTPUT_FB	input	command/actual cross-check
D9	PULSE_CMD	output	timer-owned bounded request
D10	ADC_CS	output	SPI ADC chip select
D11	SPI_MOSI	output	external ADC
D12	SPI_MISO	input	external ADC
D13	SPI_SCK	output	external ADC
A0	HW_INHIBIT	output	default-safe inhibit request
A1	CHARGE_ENABLE	output	supervised preparation request
A2	ENCLOSURE_INTLK	input	direct enclosure/service interlock
A3	EXPANDER_INT	input	shared open-drain input-expander interrupt
A4	I2C_SDA	bus	expanders, OLED, FRAM and registered local devices
A5	I2C_SCL	bus	expanders, OLED, FRAM and registered local devices
A6	HANDPIECE_PRESENT	input	direct presence indication
A7	TRIP_OC	input	independent current-trip comparator
AREF	RESERVED	-	external reference/emergency revision reserve
TX/RX	SERVICE_UART	bus	development, test and recovery diagnostics

Appendix B. I2C and SPI Registry

Interface	Device / owner	Status
I2C 0x20	panel-input MCP23017	required
I2C 0x21	panel-output MCP23017	required
I2C 0x22	machine-I/O MCP23017	required
I2C 0x3C	OLED	required
I2C 0x40-0x47	registered local machine devices	reserved
I2C 0x50	FRAM	required
I2C 0x68	optional RTC	DNP RevA
SPI D10-D13	external ADC	required

Addresses 0x23-0x27 remain reserved for future GPIO expansion and may not be used without a controlled update.

Appendix C. Talkback Behaviour

State/event	SAFE	CHARGE	READY	ARMED	OUTPUT	FAULT	ENERGY	OPR ERR
reset / unknown	off	off	off	off	off	HW	HW	off
SAFE verified	on	off	off	off	off	off	state	off
preparing	off	on	off	off	off	off	on	off
ready	off	off	on	off	off	off	on	off
armed	off	off	state	on	off	off	on	off
output feedback active	off	off	off	on	on	off	on	off
fault	state	off	off	off	off	on	state	state
rejected operator sequence	state	state	state	state	state	state	state	on

HW means hardware may assert independently. state means preserve the authoritative condition; OPR ERR does not clear system state and is reset only by the defined operator-error rule.

Appendix D. Connector Register

Connector	Baseline family / pins	Signals	Status
J-PNL	keyed IDC 2 x 10	panel power/ground, SDA, SCL, shared IRQ, reset/service and returns	frozen function
J-PWR	Micro-Fit 3.0, 12-circuit	conditioned machine commands/status only	frozen function
J-HND	Micro-Fit 3.0, 8-circuit	trigger, grip, presence, ID, temperature, shield and returns	frozen function
J-AUX	JST-XH, 6-circuit	enclosure/service/fan/status and spares	frozen function
SERVICE	board header	UART, reset, test points and ground	frozen function

Exact shell/keying subpart numbers may change before PCB release, but signal ownership and segregation may not.

References

1. Arduino, Arduino Nano Every ABX00028 official datasheet and pinout.
2. Microchip, ATmega4809 datasheet.
3. Microchip, MCP23017/MCP23S17 datasheet.
4. Microchip, MCP3208 datasheet.
5. Fujitsu, MB85RC256V datasheet.
6. Texas Instruments, ADS7953, comparator, monostable and protection-device datasheets listed in NA-MASTER-001.
7. NanoArc, NA-MASTER-001 Revision 1.2.
8. NanoArc, NA-CSHID-001 Revision A.1.
9. NanoArc, NA-ACEPVN-001 Revision A.1.

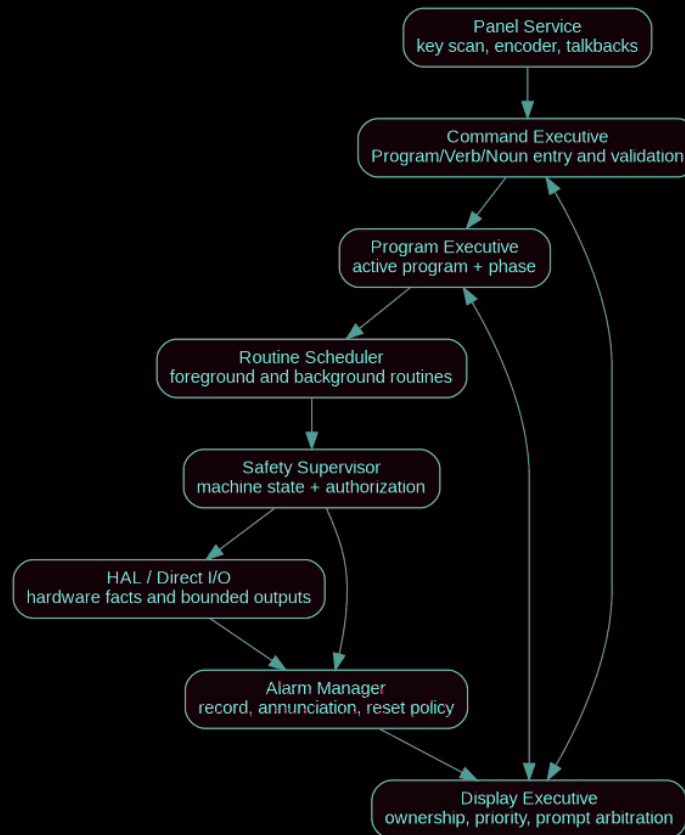
DESIGN NOTE: Manufacturer data controls electrical limits. NA-MASTER-001 controls project ownership, names, pin assignments and interface contracts.

NANOARC

ACE Program, Routine, Verb, Noun, and Operator-Flow Architecture Manual

Revision A.1 - Frozen Program, Verb, Noun and Operator-Flow Baseline

Apollo-derived operating principles adapted for the NanoArc Arc Control Executive



Field	Value
Document	NA-ACEPVN-001
Revision	A.1 / Master Revision 1.2
Date	2026-06-26
Status	Frozen RevA command and operator-flow baseline
Controller	Arduino Nano Every / ATmega4809
Source basis	Apollo 15 Delco CMC/Colossus, PDF pages 2-103

DESIGN NOTE: This manual is the implementation source of truth for Program, Routine, Verb, Noun, prompt, alarm and operator-response semantics.

Document Control

Revision	Date	Description
A.0	2026-06-24	Superseded draft containing the temporary PROG/ACK panel and conflicting alarm-Noun assignments.
A.1	2026-06-26	Frozen RevA command and flow baseline aligned with NA-MASTER-001 Revision 1.2, NA-CSHID-001 A.1 and NA-ACEHW-001 A.1.

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1. Purpose and Scope
2. CMC Analysis and Design Lessons
3. Revised ACE Executive Architecture
4. Operator-Panel Integration
5. Code Spaces and Descriptor Model
6. ACE Program Catalogue
7. ACE Routine Catalogue
8. ACE Verb Catalogue
9. ACE Noun Catalogue
10. Option, Checklist, Prompt and Alarm Tables
11. Program Operating Flows
12. Automatic Sequencing and Background Services
13. Firmware Mapping and Migration
14. Verification and Acceptance
15. Integration Impact and Deferred Decisions
Appendix A. Program/State Compatibility
Appendix B. Event Catalogue
Appendix C. Source Traceability
References

DESIGN NOTE: A.1 is the implementation source of truth for code numbers and operator responses. A.0 code assignments must not be copied into firmware.

Executive Summary

The Apollo 15 CMC material changes one central assumption in the preliminary ACE design: a Program is not a machine state. The CMC always had a major program, including its idle program P00, while hardware mode, display ownership, routines, alarms and automatic sequences existed as separate dimensions. ACE shall adopt the same separation in a modern typed architecture.

The resulting design retains the NanoArc safety boundary while adding a Program Executive, Routine Scheduler, Command Executive, Display Executive, Prompt Manager and table-driven data dictionary. The previous direct transition SAFE + PROGRAM_REQUEST -\> PROGRAM is therefore superseded. Program requests are validated and dispatched independently from the Safety Supervisor.

The CMC structure is used as a design pattern, not copied literally. ACE keeps decimal two-digit codes and logical R1/R2/R3 components, but uses an OLED, typed descriptors, explicit access control and modern fault containment.

1. Purpose and Scope

This manual defines the operator-visible program structure and the firmware architecture that supports it. It integrates lessons from the Apollo 15 CMC/Colossus operating procedures into the existing NanoArc ACE control-system and operator-panel design.

- Define the distinction between machine state, active Program, routine execution and authorization state.
- Define the Program, Routine, Verb, Noun, Option, Checklist, Prompt and Alarm code spaces.
- Define display ownership, flashing prompts, operator responses and program recycling.
- Define the frozen Program catalogue and detailed flow for RevA control-module development.
- Define the firmware descriptor tables and event routing required to implement the interface without dynamic allocation.
- Bind command behavior to the NA-ACEHW-001 A.1 panel and I/O baseline.

The manual does not define the high-current output stage, capacitor-bank construction or final process parameters. Nouns that refer to energy or pulse characteristics are interfaces whose numerical limits remain provisional until hardware characterization is complete.

2. CMC Analysis and Design Lessons

2.1 Source boundary

The analysis covers the CMC/Colossus section of the Apollo 15 Delco manual, PDF pages 2 through 103. The LGC/Luminary section begins on PDF page 104 and is intentionally outside this revision. The source includes DSKY behaviour, Program and Routine catalogues, complete Verb and Noun tables, option/checklist/alarm codes, display arbitration flagwords, channel assignments, detailed Program procedures and the R07 MINKEY automatic sequencer \[1].

2.2 Structural findings

- P00 is an idling Program, proving that a program can remain active while the machine is merely waiting.
- Major Programs own long-lived mission procedures; reusable Routines perform shared operations and displays.
- Regular Verbs are highly systematic: display, monitor, load, recycle, proceed, terminate, test, restart and change Program.
- Nouns are data descriptors with one to three components, units, formats and load restrictions.
- Option codes and checklist codes are separate namespaces rather than overloaded Nouns.
- Flashing displays are response contracts. PRO, ENTR, KEY REL and RSET have different meanings.
- Display ownership is arbitrated. Internal priority displays can be held while the operator owns the keyboard.
- Programs can call background routines or coexist with other functions; P20 is a clear example.
- Automatic sequencing is implemented above individual Programs by R07 MINKEY.
- Program changes can be inhibited during critical computations; invalid requests raise an operator-visible error.

2.3 Patterns adopted by ACE

CMC pattern	ACE adaptation
P00 idling program	P00 SAFE IDLE becomes the default active Program after startup.
Programs separate from hardware modes	ProgramCode is independent from MachineState and AuthorizationState.
Routines	Reusable services receive RoutineCode values and completion events.
Regular Verb families	V01-06 display, V11-16 monitor, V21-25 load, V32-37 executive control.
Three-component Nouns	Each Noun has zero to three typed components with units, range and access policy.
Flashing display	PromptDescriptor defines response type, priority, timeout and fallback.
KEY REL / OPR ERR	Panel gains KEY REL and OPR ERR semantics; invalid sequences cannot silently disappear.
Option and checklist codes	Separate descriptor tables support choices and physical operator actions.
MINKEY sequencer	R07 Automatic Sequence Controller performs multi-Program flows.
Alarm history	ACE records first, second and latest alarm plus persistent history.

2.4 Patterns deliberately rejected

- No operator Verb may write arbitrary memory or raw hardware channels in normal builds.
- No Program directly drives a safety-critical output; it requests a bounded service through the Supervisor and HAL.
- No restart may restore an armed or active-output condition.
- No hidden, untyped FLAGWORD maze is used as the primary software

model. Typed facts and compact bitsets replace it.

- No display-only confirmation can arm or enable the physical output path.
- No fixed five-digit octal presentation is required; display formatting is selected by each Noun descriptor.

3. Revised ACE Executive Architecture

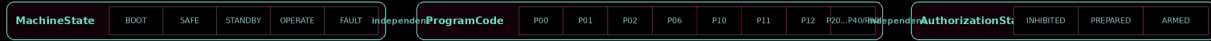


Figure 2. Machine state, Program state and authorization state are independent.

3.1 Three independent state dimensions

Dimension	Owner	Baseline values
Machine state	Safety Supervisor	BOOT, SAFE, STANDBY, OPERATE, FAULT
Active Program	Program Executive	P00, P01, P06, P10, P11, P20, P30, ...
Authorization	Safety Supervisor / hardware facts	INHIBITED, PREPARED, ARMED
Program phase	Active Program instance	Program-specific phase code
Output fact	HAL feedback	inactive or active; never inferred from Program alone

Any residual `MachineState::program` implementation is superseded and must be replaced by `MachineState::OPERATE`. Program selection is tracked separately by `ProgramExecutive`. After `BOOT_COMPLETE`, the Supervisor enters `SAFE` and `ProgramExecutive` starts `P00`.

3.2 Program Executive

- Owns the active Program code and current phase.
- Validates manual and automatic Program requests against a `ProgramDescriptor`.
- Performs explicit entry, suspend, resume, terminate and fallback actions.
- Posts `program_started`, `program_phase_changed`, `program_completed` and `program_aborted` events.
- Never changes safety authorization directly; it submits requests to the Supervisor.

3.3 Routine Scheduler

- Runs short reusable Routines without pretending that each Routine is a major Program.
- Supports one foreground Routine owned by the active Program and a bounded set of background services.
- Rejects duplicate ownership of exclusive hardware services.
- Uses completion events rather than blocking calls or nested modal loops.

3.4 Command Executive



Figure 3. Table-driven command construction and dispatch.

- Builds ordinary commands from VERB, NOUN, digit, sign, CLR and ENTR key events. V37 creates a separate two-digit Program-entry phase; there is no Program key event.
- Validates Verb existence, Noun existence, component compatibility, access policy, Program permission and machine-state permission.
- Stages writes before commit. A partially entered value never changes the live system.
- Reports operator errors through `OPR_ERR`, an error message and a rejected-command event.

3.5 Display Executive and Prompt Manager

- Own the logical R1/R2/R3 image and OLED composition.

- Arbitrate operator entry, monitors, Program prompts, safety prompts and alarm detail.
- Preserve one interrupted `DisplayContext`; additional pressure is represented by priority and a bounded pending owner, never an unbounded stack.
- Interpret only `ENTR`, `PRO`, `KEY REL` and `RSET` as prompt responses in RevA.
- `KEY REL` restores the prior nonblocking context or the active Program default page.
- `CLR` belongs to staged command editing unless a prompt descriptor explicitly allows cancellation.

3.6 Alarm Manager

- Records active alarms plus first, second and latest codes for V05 N09.
- Drives `FAULT` presentation; `OPR ERR` is owned by `CommandExecutive/PanelService` for rejected operator sequences.
- `RSET` clears only eligible annunciation state after the source condition is absent.
- `KEY REL` may leave an alarm-detail page but never clears the cause or authorization state.
- Persists versioned alarm/restart records to FRAM through the storage service.
- There is no `AlarmAck` event and no generic acknowledgement state in RevA.

4. Operator-Panel Integration

The frozen panel is a 4-row by 5-column matrix. It retains the distinct Apollo-style PRO, ENTR, KEY REL and RSET semantics while removing the unnecessary PROG and generic ACK keys.

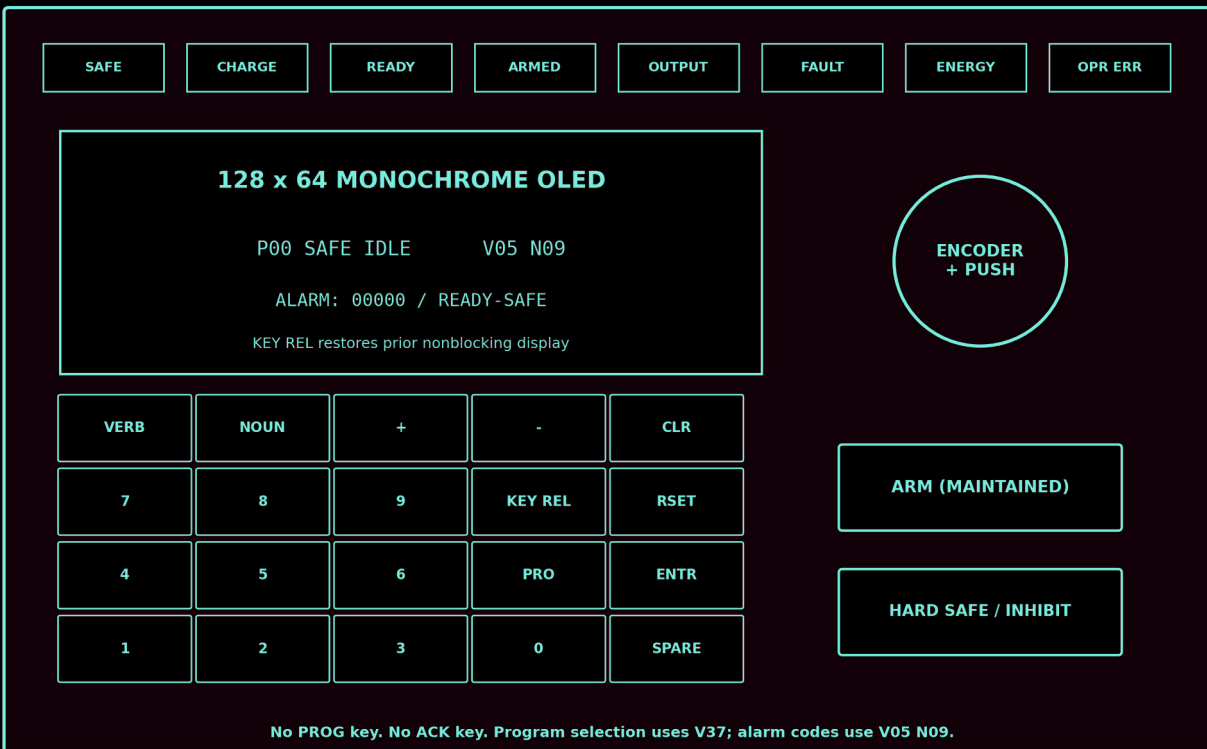


Figure 4. Frozen 4 x 5 panel and eight-talkback baseline.

4.1 Keypad matrix

Row	C0	C1	C2	C3	C4
R0	VERB	NOUN	+	-	CLR
R1	7	8	9	KEY REL	RSET
R2	4	5	6	PRO	ENTR
R3	1	2	3	0	SPARE

The matrix consumes nine expander lines. Encoder A/B/push and panel-present bring the 0x20 input expander to thirteen used lines with three spares.

Program selection is VERB 3 7 ENTR, two Program digits, ENTR - the physical V37E##E sequence.

4.2 Key semantics

Key	ACE meaning
VERB / NOUN	Select the corresponding two-digit field.
0-9	Enter digits into the selected field/component.
+ / -	Select explicit sign for a signed component.
CLR	Clear staged data or cancel an incomplete entry.
ENTR	Commit a command/data component or answer an ENTR prompt.
PRO	Proceed/approve the active Program prompt without pretending data were entered.
KEY REL	Relinquish the temporary/internal detail page and restore the prior nonblocking context.
RSET	Clear eligible annunciation after the cause clears; never bypass a fault.

Key	ACE meaning
Encoder	Browse and edit bounded values; push is local selection only.

4.3 Talkbacks

SAFE, CHARGE, READY, ARMED, OUTPUT, FAULT, ENERGY and OPR ERR are the eight frozen talkbacks. OPR ERR reports a rejected operator sequence; it is not a general alarm-acknowledgement lamp.

4.4 Logical registers on the OLED

- Logical R1, R2 and R3 remain the Noun component model.
- Every component has label, value, unit and validity state.
- Program, Verb and Noun codes remain visible in the header.
- Flashing is reserved for a response contract.

4.5 Display ownership and priority

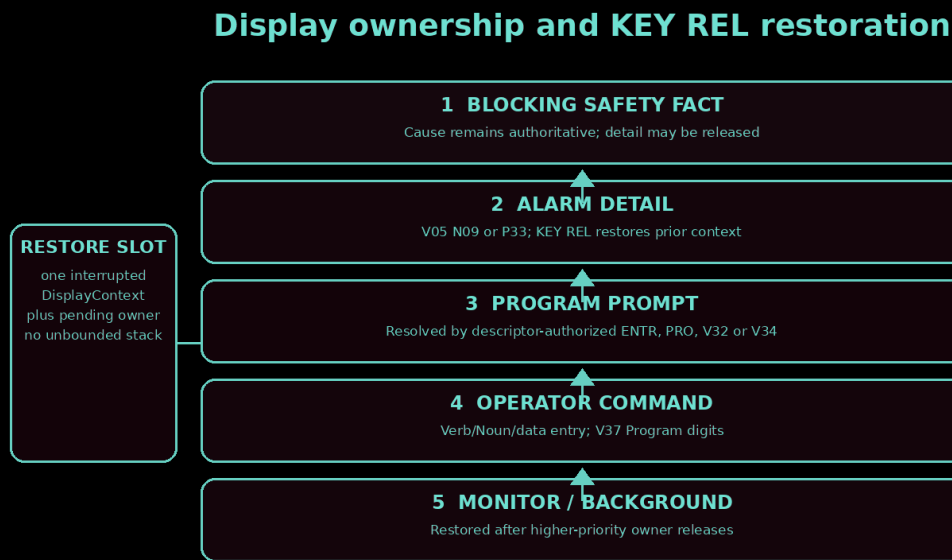


Figure 5. Bounded display ownership and KEY REL restoration.

Priority	Owner	Resolution
1	Blocking safety fact	Required physical condition remains authoritative.
2	Alarm detail	V05 N09 or P33; KEY REL restores prior context; RSET only if eligible and clear.
3	Active Program prompt	Descriptor-authorized ENTR, PRO, V32 or V34.
4	Operator command entry	ENTR commit, CLR edit/cancel, KEY REL release where permitted.
5	Monitor/background	Replaced by higher priority and restored afterward.

5. Code Spaces and Descriptor Model

5.1 Code types

using ProgramCode = uint8_t; using RoutineCode = uint8_t; using VerbCode = uint8_t; using NounCode = uint8_t; using OptionCode = uint16_t; using ChecklistCode = uint16_t; using PromptCode = uint16_t; using AlarmCode = uint16_t;

Two-digit Program, Routine, Verb and Noun codes are operator-visible decimal values. Option, Checklist, Prompt and Alarm codes may use wider numeric ranges. Strong wrapper types or enum classes should prevent accidental interchange in firmware.

5.2 Descriptor relationships

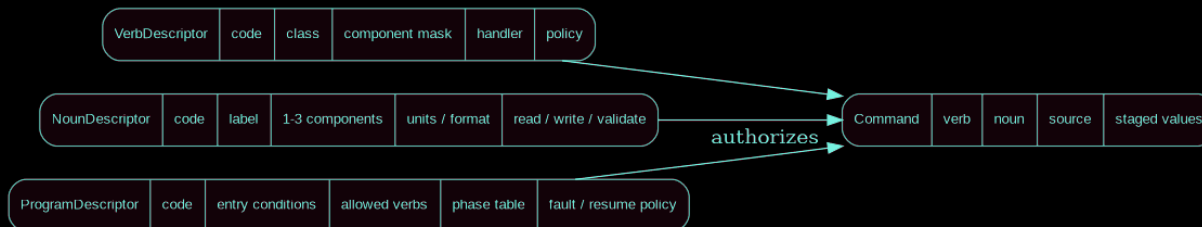


Figure 6. Commands are validated against immutable Verb, Noun and Program descriptors.

Descriptor	Required fields
ProgramDescriptor	code, title, entry states, allowed Programs, allowed Verb mask, phase table, fallback Program, restart policy
RoutineDescriptor	code, title, exclusivity class, request event, completion event, timeout, abort policy
VerbDescriptor	code, class, component mask, access operation, handler/request type, prompt behaviour
NounDescriptor	code, title, component count, component descriptors, read/write/validate hooks, Program/state permissions
ComponentDescriptor	label, data type, scale, units, format, min, max, sign rule, persistence and source
PromptDescriptor	code, priority, required response, flashing fields, timeout, default action and cancel path
AlarmDescriptor	code, subsystem, severity, latch policy, reset rule, default display and safe action

5.3 Storage policy

- Immutable descriptor tables and strings live in flash memory.
- RAM holds only the active Program instance, one foreground Routine, bounded background-service state, the current command builder, active prompt and current display values.
- No heap allocation is permitted in the executive path.
- Every table has an explicit count and compile-time uniqueness test where practical.

6. ACE Program Catalogue

6.1 Allocation policy

Range	Class
P00-P09	Executive, startup, recovery and standby
P10-P19	Normal operation and simulation
P20-P29	Profiles, tools and calibration
P30-P39	Status, diagnostics and logs
P40-P49	Restricted service and factory functions
P50-P89	Reserved
P90-P99	Development-only harnesses; removed from release builds

6.2 Baseline catalogue

Code	Program	Status	Purpose
P00	SAFE IDLE	Baseline	Default readiness state, command entry and safe monitoring.
P01	STARTUP SELF-TEST	Internal	Validate firmware invariants, panel presence, buses, storage and direct safety facts.
P02	RECOVERY	Internal	Interpret reset cause, reconstruct safe persistent state and return to P00 or FAULT.
P06	STANDBY / POWER-DOWN	Baseline	Enter low-activity standby while preserving safe restart behaviour.
P10	SINGLE OPERATION	Baseline	Prepare and execute one authorized operation, capture result and return to P00.
P11	REPEAT JOB SESSION	Planned	Sequence repeated P10-equivalent cycles with counters, interval and cooldown policy.
P12	DRY RUN / SIMULATION	Baseline	Exercise the complete command and Program flow while all physical output remains inhibited.
P20	PROFILE SELECT / REVIEW	Baseline	Browse, inspect and select a stored or temporary profile.
P21	PROFILE EDIT	Planned	Edit a working copy, validate and commit to storage.
P22	MATERIAL CALIBRATION	Future	Collect controlled test results and derive provisional profile data.
P23	SENSOR CALIBRATION	Planned	Calibrate low-voltage sensing channels against references.
P24	TOOL CONFIGURATION	Planned	Select and verify electrode/tool configuration and reference values.
P30	SYSTEM STATUS	Baseline	Read-only live status and measurement monitoring.
P31	PANEL TEST	Baseline	Test keypad, encoder, OLED, talkbacks and sounder without energizing output hardware.
P32	I/O DIAGNOSTICS	Baseline	Inspect direct inputs, feedback and bus devices; output tests remain bounded and safe.
P33	ALARM / RESTART REVIEW	Baseline	Inspect active alarm, history, reset cause and clearing conditions.
P34	STORAGE INTEGRITY	Planned	Verify profile and log records,

Code	Program	Status	Purpose
			checksums and directory consistency.
P40	SERVICE MODE	Restricted	Authorized maintenance functions requiring an explicit service build or hardware condition.
P90	DEVELOPMENT HARNESS	Development	Synthetic events, simulated sensors and deterministic test sequences; excluded from release firmware.

6.3 Program-request rules

- P00 is automatically selected after successful startup and after normal Program termination.
- A Program request is rejected if its descriptor disallows the current MachineState, authorization state or active fault condition.
- A Program request never directly changes the Safety Supervisor state. Entry code requests any needed transition and waits for approval.
- Only P01 and P02 may run during BOOT. Read-only P30 and P33 may be available in FAULT.
- P10 and P11 may enter from SAFE but require OPERATE before preparation can proceed.
- Program changes are inhibited during a timed action and other descriptor-marked critical phases.

7. ACE Routine Catalogue

Code	Routine	Purpose
R00	FINAL REQUEST / RETURN P00	Terminate current function and request the Program fallback path.
R01	COMMAND ENTRY	Build and edit Program/Verb/Noun commands.
R02	HARDWARE FACT SAMPLE	Acquire direct and bus-based low-voltage facts into a coherent snapshot.
R03	STARTUP TEST	Execute startup invariant and device-presence checks.
R04	DISPLAY SERVICE	Compose logical registers and OLED pages.
R05	PANEL SERVICE	Scan keypad/encoder, debounce and update talkbacks.
R06	ALARM SERVICE	Record alarms, select priority display and apply latch policy.
R07	AUTOMATIC SEQUENCE CONTROLLER	Execute bounded tables of Program/Routine steps and conditions.
R10	PROFILE LOAD	Load a profile into a working context.
R11	PROFILE VALIDATE	Validate ranges, integrity, hardware compatibility and revision.
R12	READINESS EVALUATE	Combine profile, hardware, contact, cooldown and authorization facts.
R13	CONTACT TEST	Request and evaluate a low-energy contact/readiness measurement interface.
R14	PREPARATION SERVICE	Prepare the requested operation within Supervisor limits.
R15	TIMED ACTION SERVICE	Own the bounded timing request and independent cutoff interface.
R16	POST-ACTION CAPTURE	Capture measured results and hardware feedback.
R17	COOLDOWN MANAGER	Enforce time and temperature recovery policy.
R20	PROFILE EDITOR	Stage component edits and validation.
R21	MATERIAL CALIBRATION ENGINE	Collect calibration samples and calculate provisional results.
R22	SENSOR CALIBRATION ENGINE	Calculate and verify sensor offset/scale records.
R23	TOOL CONFIGURATION	Validate electrode/tool identity and references.
R30	STATUS DISPLAY	Provide the P30 default monitor page.
R31	ALARM DISPLAY	Provide active and historical alarm pages.
R32	PANEL TEST	Exercise panel hardware in a safe pattern.
R33	I/O TEST	Observe direct I/O and bounded feedback tests.
R34	BUS RECOVERY	Perform bounded I2C recovery and device rescan.
R35	STORAGE INTEGRITY	Verify directories, record headers and checksums.
R40	RESTART RECONSTRUCTION	Interpret reset records and restore safe, non-armed state.

R07 is the ACE equivalent of the CMC MINKEY pattern. It coordinates major steps but does not absorb their implementation. Each called Program or Routine still owns its own entry checks and completion event.

8. ACE Verb Catalogue

8.1 Regular Verbs

Code	Meaning
V00	Invalid / unused
V01	Display component 1
V02	Display component 2
V03	Display component 3
V04	Display components 1 and 2
V05	Display components 1, 2 and 3
V06	Display Noun using its normal formatted page
V07	Display raw diagnostic representation - restricted
V08-V10	Reserved
V11	Monitor component 1
V12	Monitor component 2
V13	Monitor component 3
V14	Monitor components 1 and 2
V15	Monitor components 1, 2 and 3
V16	Monitor Noun using its normal formatted page
V17	Monitor raw diagnostic representation - restricted
V18-V20	Reserved
V21	Load component 1
V22	Load component 2
V23	Load component 3
V24	Load components 1 and 2
V25	Load components 1, 2 and 3
V26	Validate staged load without committing
V27	Display Noun descriptor metadata
V28-V29	Reserved
V30	Request a Routine by code
V31	Schedule a permitted deferred Routine
V32	Recycle the current Program phase
V33	Proceed without changing displayed data
V34	Terminate the current Routine or Program through its defined exit
V35	Panel/lamp test
V36	Controlled software restart to inhibited recovery
V37	Change major Program
V38	Display contextual help
V39	Reserved

8.2 Extended Verb ranges

Range	Domain
V40-V49	Profile, calibration and reference operations
V50-V59	Internal checklist/prompt presentation; firmware-generated
V60-V69	Bounded service and result operations
V70-V89	Reserved for controlled future allocation

Range	Domain
V90-V99	Factory/development only; excluded from release builds

8.3 Initial extended Verbs

Code	Meaning
V40	Zero selected calibration quantity
V41	Calibrate selected Noun/channel
V42	Capture reference sample
V43	Select active profile
V44	Save working profile
V45	Load profile
V46	Copy profile
V47	Delete eligible profile
V48	Validate profile
V49	Restore documented defaults
V50	Present a checklist / “please perform” request
V51-V59	Internal prompt variants; not unrestricted operator commands
V60	Request contact test
V61	Request preparation service
V62	Abort preparation and return safe
V63	Accept current result/disposition where descriptor permits
V64	Request panel test
V65	Request I/O diagnostics
V66	Request bus recovery/rescan
V67	Request storage integrity test
V68-V89	Reserved
V90-V99	Development/factory functions

Alarm-code retrieval is V05 N09; annunciation reset is the physical RSET key. No V58 “acknowledge” or V72 duplicate reset exists in RevA.

8.4 Verb safety rules

- No Verb means ARM, FIRE, BYPASS, FORCE OUTPUT or IGNORE FAULT.
- V21-V25 only stage writable Noun components and commit atomically after validation.
- V32 returns to a Program-defined recycle point; it is not an arbitrary jump.
- V34 follows the active Program/Routine safe exit and cannot defeat the independent cutoff service.
- V36 always enters inhibited recovery and cannot resume authorization.
- V37 is the only normal Program-selection Verb.
- V50-V59 are firmware-generated prompt displays, not free-standing operator privileges.
- V05 N09 and P33 are the alarm-inspection paths; RSET is the only normal annunciation-reset control.

9. ACE Noun Catalogue

9.1 Noun descriptor requirements

Every Noun has zero to three typed components declaring scale, unit, format, range, sign, validity, source and access. Writable values are staged and validated; measurements and safety facts are load-locked.

Executive and command nouns

Code	Noun	Components	Access
N00	Invalid / unused	-	none
N01	Machine status	state; authorization; readiness	read-only
N02	Active Program	Program; phase; progress	read-only
N03	Active profile	slot; profile code; validity	read/select
N04	Command state	Verb; Noun; entry status	read-only
N05	Prompt state	prompt; required response; priority	read-only
N06	Option request	option ID; selection; validity	read/select
N07	Checklist request	code; status; source	read-only
N08	Executive resources	queue depth; rejected; high-water	read-only
N09	Alarm codes	first; second; latest	read-only

Power, safety and hardware facts

Code	Noun	Components	Access
N10	Supply status	source; input voltage; logic rail	read-only
N11	Energy status	measured level; target; condition	read-only
N12	Temperatures	bank; stage; ACE/handpiece selection	read-only
N13	Interlocks	hard-safe/arm; grip/trigger; enclosure/presence	read-only
N14	Output path	inhibit; command; feedback	read-only
N15	Readiness	profile; hardware; cooldown/contact	read-only
N16	Bus status	I2C; SPI ADC; recovery/fault count	read-only
N17	Panel status	last key; encoder; panel health	read-only
N18	Reset status	cause; count; recovery result	read-only
N19	Reserved	-	none

Profile and configuration nouns

Code	Noun	Components	Access
N20	Profile identity	slot; profile code; revision	read/select
N21	Material pair	material A; material B; class	read/write in P21/P22
N22	Action parameters	target; duration; stage count	read/write in P21; limits provisional
N23	Tool configuration	electrode type; spacing; revision	read/write in P21/P24
N24	Repetition policy	count; interval; cooldown	read/write in P21
N25	Profile integrity	format; CRC; compatibility	read-only
N26	Contact criteria	measured value; threshold; result	restricted
N27	Preparation policy	target; limit; timeout	restricted
N28	Operation limits	duration; energy; temperature	restricted
N29	Profile flags	source; validity flags; dirty state	read-only

Operation and result nouns

Code	Noun	Components	Access
N30	Current job	job ID; cycle; state	read-only
N31	Operation request	profile; mode; sequence ID	read-only
N32	Operation result	duration; peak/current result; delivered result	read-only
N33	Quality result	pre-contact; post-contact; disposition	read/select disposition
N34	Timing statistics	preparation; action; cooldown	read-only
N35	Cycle counters	session; lifetime; failures	read-only
N36	Last operation fault	code; phase; recovery	read-only
N37	Simulation result	expected path; blocked step; reason	read-only

Measurement and calibration nouns

Code	Noun	Components	Access
N40	Raw sensor group A	bank; charge current; bank temperature	restricted read
N41	Raw sensor group B	output current; stage/tool temperature; auxiliary	restricted read
N42	Calibrated measurements	selected voltage; current; temperature	read-only
N43	Calibration coefficients	offset; scale; revision	restricted
N44	Comparator / trip status	OV; OC; FAULT_SUM/source latch	read-only
N45	Timing capture	start tick; stop tick; clamp margin	read-only

Alarm, log and service nouns

Code	Noun	Components	Access
N50	Current alarm	code; source; active/clear state	read-only
N51	Alarm-history entry	cursor/index; code; state/time token	read/select cursor
N52	Alarm counts	active; session; lifetime	read-only
N53	Inhibit reason	primary; secondary; clear condition	read-only
N54	Restart record	cause; Program/phase; result	read-only
N55	Event-history cursor	index; type; timestamp token	read/select
N56	Service request	code; severity; required action	read-only
N57-N59	Reserved	-	none

Diagnostic and identity nouns

Code	Noun	Components	Access
N60	Panel diagnostics	keypad; encoder; talkbacks	read-only
N61	Display diagnostics	controller; update rate; errors	read-only
N62	Bus diagnostics	bus; device; fault count	read-only
N63	Direct I/O diagnostics	inputs; outputs; mismatch	read-only
N64	Storage diagnostics	slots; valid records; errors	read-only
N65	Firmware build	version; build ID; schema	read-only
N66	Resource status	SRAM; queue high-water; uptime	read-only
N67	Hardware identity	controller; panel/MIO; unit ID	read-only
N68	Test selection	test code; iterations; result	read/select

Code	Noun	Components	Access
N69	Test detail	step; measured; expected	read-only

Calibration working nouns

Code	Noun	Components	Access
N80	Calibration selection	channel; method; reference	read/select
N81	Calibration coefficients	offset; scale; checksum	restricted
N82	Calibration sample	raw; reference; residual	restricted
N83	Calibration result	channel; pass/fail; revision	read-only
N84	Tool reference	type; resistance/reference; revision	restricted
N85	Material calibration	pair; sample; result	restricted
N86-N89	Reserved	-	none
N90-N99	Development/factory	build-specific	restricted

10. Option, Checklist, Prompt and Alarm Tables

10.1 Option codes

Code	Purpose	Choices
O001	Operation mode	1 single; 2 repeat; 3 simulation
O002	Profile source	1 stored; 2 temporary; 3 documented default
O003	Contact-test sensitivity	1 normal; 2 sensitive; 3 characterization
O004	Monitor refresh	1 slow; 2 normal; 3 fast
O005	Result disposition	1 accept; 2 retry; 3 reject/record
O006	Calibration method	1 verification; 2 one-point; 3 two-point
O007	Standby policy	1 display on; 2 dim; 3 low-power

10.2 Checklist codes

Code	Operator action
C001	Set HARD SAFE
C002	Release trigger
C003	Connect handpiece/control cable
C004	Install the specified electrode/tool
C005	Place the test article or workpiece
C006	Remove the workpiece
C007	Wait for cooldown
C008	Connect the specified calibration reference
C009	Inspect and classify the result
C010	Disconnect output hardware before service

10.3 Prompt codes

Code	Prompt	Allowed response
Q001	Confirm Program start	PRO or V34
Q002	Accept staged data	ENTR, V32 or CLR
Q003	Set HARD SAFE	physical action then PRO
Q004	Release trigger	physical action; automatic completion
Q005	Arm when READY	physical action; no display command substitutes
Q006	Inspect result	PRO/V63 to accept or V32 to recycle/reject
Q007	Review fault detail	KEY REL to leave detail; RSET only if eligible and clear
Q008	Reset eligible annunciation	RSET after cause clears
Q009	Release display ownership	KEY REL

10.4 Alarm-code allocation

Range	Subsystem	Examples
1000-1999	Executive and scheduling	startup invariant; queue admission; ownership conflict
2000-2999	Panel and buses	required device missing; I2C/SPI recovery failed
3000-3999	Measurements and sensors	invalid range; stale channel; calibration invalid
4000-4999	Safety and interlocks	trigger active at request; trip; feedback mismatch

Range	Subsystem	Examples
5000-5999	Profiles and storage	schema/CRC incompatibility; directory error
6000-6999	Preparation and timed action	preparation timeout; independent clamp termination
7000-7999	Reset and power	brownout; watchdog; unexpected reset
8000-8999	Service and diagnostics	self-test or loopback failure
9000-9999	Development only	synthetic fault injection

V05 N09 always presents first, second and latest codes. N50 presents the current alarm detail, N51 browses persistent history through P33, and RSET only clears an eligible annunciation after its source is absent.

11. Program Operating Flows

Each Program specification follows the Delco structure: Purpose, Assumptions/Entry Conditions, Sequence of Events and Exit/Recycle Behaviour. The flows below are the RevA architecture baseline; exact process limits remain external configuration.

P00 - SAFE IDLE

Purpose. Maintain ACE in a safe, responsive condition while accepting commands and monitoring hardware facts.

Assumptions / entry conditions.

- Startup or recovery completed successfully.
- Safety Supervisor is SAFE or STANDBY; authorization is INHIBITED.
- No timed action is active.

Sequence of events.

1. Select P00 automatically.
2. Assert the software inhibit request and show SAFE.
3. Run R02 hardware-fact sampling, R04 display service, R05 panel service and R06 alarm service.
4. Display N01/N02 default status.
5. Accept permitted Program, Verb and Noun commands.

Exit and recycle behaviour.

- Valid Program request transfers through Program Executive entry checks.
- Active blocking fault transfers to FAULT display while P00 remains the fallback Program.
- P06 request enters standby.

P01 - STARTUP SELF-TEST

Purpose. Prove control-module invariants before normal command acceptance.

Assumptions / entry conditions.

- Entered only from BOOT.
- Output hardware remains independently inhibited.

Sequence of events.

1. Run static/runtime invariant checks.
2. Verify queue, program table and descriptor-table integrity.
3. Verify panel and required bus devices.
4. Read reset cause and direct safety inputs.
5. Verify storage headers and load defaults.
6. If all mandatory checks pass, post BOOT_COMPLETE and start P00;
otherwise raise an alarm and remain inhibited.

Exit and recycle behaviour.

- P01 cannot be selected manually in release firmware.
- Failure enters FAULT or restricted P30/P33 visibility.

P02 - RECOVERY

Purpose. Recover from reset without recreating an unsafe operating condition.

Assumptions / entry conditions.

- Entered automatically after watchdog, brownout or software restart.
- Authorization state is forced to INHIBITED before persistent data are interpreted.

Sequence of events.

- | |
|--|
| 1. Capture reset cause and previous Program record. |
| 2. Validate persistent configuration and alarm record. |
| 3. Reconstruct only non-hazardous session state. |
| 4. Run the required subset of P01 checks. |
| 5. Record recovery result in N54. |
| 6. Return to P00 or enter FAULT. |

Exit and recycle behaviour.

- Never restores ARMED, OUTPUT or an unfinished timed action.
- Operator must explicitly reselect any prior Program.

P06 - STANDBY / POWER-DOWN

Purpose. Reduce control-module activity while preserving deterministic wake-up and safe state.

Assumptions / entry conditions.

- Entered from P00 with no active fault requiring display ownership.
- Authorization is INHIBITED.

Sequence of events.

- | |
|---|
| 1. Prompt for confirmation. |
| 2. Blank or dim nonessential display elements. |
| 3. Stop optional monitors and retain minimal panel wake path. |
| 4. Maintain required watchdog, energy-presence and fault indications. |
| 5. Wake on permitted panel or power event. |
| 6. Run wake checks and return P00. |

Exit and recycle behaviour.

- Any detected fault wakes the panel into the fault display.
- Standby never disables independent hazard indication.

P10 - SINGLE OPERATION

Purpose. Prepare and execute one authorized operation using the selected profile, then capture and present the result.

Assumptions / entry conditions.

- Active profile exists and passes R11 validation.
- Entry begins in SAFE; Supervisor must authorize OPERATE before preparation.
- Physical arm, grip and trigger facts are direct inputs, not command values.

Sequence of events.

- | |
|---|
| 1. Load and validate the active profile. |
| 2. Sample hardware facts and evaluate readiness. |
| 3. Run bounded preparation service. |
| 4. Present READY-SAFE status and wait for required physical conditions. |
| 5. Evaluate contact/readiness criteria. |
| 6. Submit a timed action request to R15. |

7. Capture feedback and result data.
8. Apply cooldown policy.
9. Present result and disposition prompt.
10. Return P00.

Exit and recycle behaviour.

- V32 recycles only to the last safe checkpoint.
- V34 terminates through inhibit and safe cleanup.
- Any failed invariant or hardware mismatch asserts inhibit and raises an alarm.

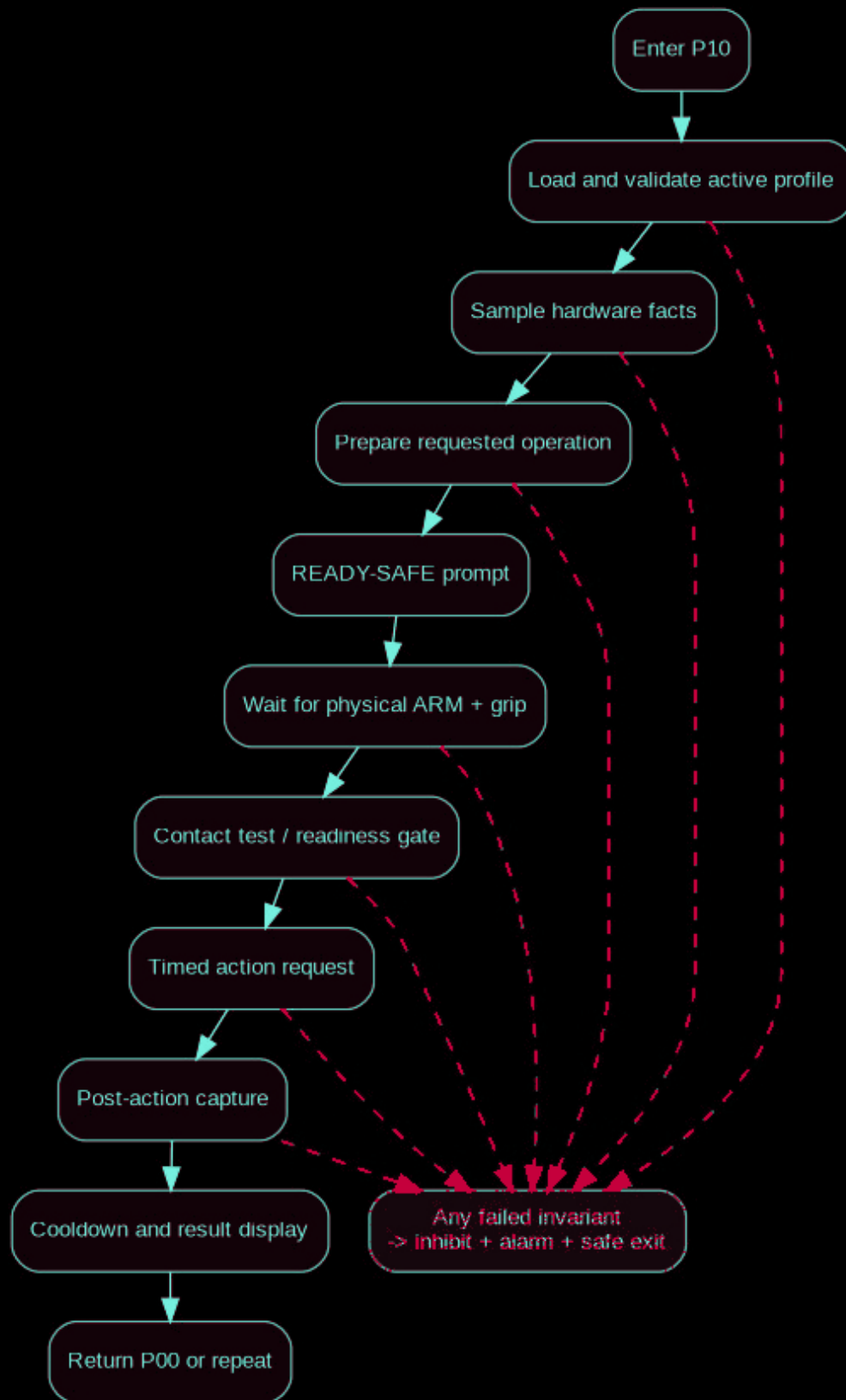


Figure 7. P10 single-operation control flow.

P11 - REPEAT JOB SESSION

Purpose. Repeat the P10 operation flow under a bounded count, interval and cooldown policy.

Assumptions / entry conditions.

- P24 repetition policy is valid.
- P10 entry requirements are satisfied for every cycle.

Sequence of events.

1. Create a job/session record.
2. Use R07 to invoke the P10 preparation/action/result stages.
3. Increment N35 counters after each completed cycle.
4. Apply interval and cooldown checks.
5. Pause on operator result, fault or readiness loss.
6. Complete at requested count or operator termination.

Exit and recycle behaviour.

- No automatic retry after a safety fault.
- A rejected cycle does not silently advance the completed-count field.
- Termination returns P00 with session summary.

P12 - DRY RUN / SIMULATION

Purpose. Exercise Program, command, prompt, display, alarm and sequencing paths without permitting physical output.

Assumptions / entry conditions.

- Development or authorized diagnostic build.
- Supervisor remains SAFE and authorization remains INHIBITED.

Sequence of events.

1. Load a selected profile and synthetic hardware-fact set.
2. Execute the P10 phase table using simulated completion events.
3. Display every required prompt and transition.
4. Record the first blocked or invalid transition in N37.
5. Return P00 with a simulation report.

Exit and recycle behaviour.

- No HAL path capable of active output is called.
- Simulation events are clearly marked and cannot enter persistent production counters.

P20 - PROFILE SELECT / REVIEW

Purpose. Browse and select a valid profile without editing live records.

Assumptions / entry conditions.

- Machine state SAFE or STANDBY.
- No profile-storage fault is active.

Sequence of events.

1. Display profile directory.
2. Select a slot with encoder or N20.
3. Load the profile into a read-only working view.
4. Display N21-N29 pages.
5. Validate compatibility.
6. Commit the active-profile selection with PRO/ENTR.
7. Return P00.

Exit and recycle behaviour.

- Invalid profiles remain viewable with reason but cannot become active.
- CLR or V34 returns without changing selection.

P21 - PROFILE EDIT

Purpose. Edit a working copy, validate it and commit an atomic profile record.

Assumptions / entry conditions.

- Machine state SAFE.
- Storage is healthy and a writable slot is selected.

Sequence of events.

1. Copy source profile or defaults into a working record.
2. Edit writable components using V21-V25.
3. Validate each component and the complete profile.
4. Display differences and integrity result.
5. Prompt to save.
6. Write a new revision atomically and verify checksum.
7. Optionally select the saved profile.
8. Return P20 or P00.

Exit and recycle behaviour.

- Live profile is unchanged until the final atomic commit.
- V32 discards the current field; V34 discards the whole working copy after confirmation.

P22 - MATERIAL CALIBRATION

Purpose. Collect controlled samples and create provisional material-pair data.

Assumptions / entry conditions.

- Restricted mode and documented test setup.
- Calibration reference and tool configuration are valid.

Sequence of events.

1. Select material pair and method.
2. Request checklist actions.
3. Collect bounded samples through existing measurement/action services.
4. Reject outliers according to a documented rule.
5. Calculate provisional values and confidence.
6. Present result for acceptance.
7. Store only as a new provisional profile revision.

Exit and recycle behaviour.

- No calibration result overwrites a validated profile automatically.
- Faults terminate the sequence and retain an incomplete record for diagnosis.

P23 - SENSOR CALIBRATION

Purpose. Derive and verify calibration coefficients for low-voltage measurement channels.

Assumptions / entry conditions.

- Machine SAFE; physical output disabled.
- Specified references are connected.

Sequence of events.

1. Select channel and calibration method.

2. Capture raw/reference pairs.

3. Compute offset and scale.

4. Verify residual and range.

5. Write a versioned calibration record.
--

6. Re-read and verify checksum.

7. Return P30 or P00.

Exit and recycle behaviour.

- Failed verification leaves the previous valid record active.
- Restricted channels require a service condition.

P24 - TOOL CONFIGURATION

Purpose. Select and verify electrode/tool identity and reference data.

Assumptions / entry conditions.

- Machine SAFE.
- Tool identity mechanism may be manual in RevA.

Sequence of events.

1. Select tool type and revision.

2. Load expected geometry/reference values.

3. Optionally perform a contact/reference check.
--

4. Validate compatibility with active profile.
--

5. Commit the working selection.

6. Return P00 or P20.

Exit and recycle behaviour.

- Incompatible tool/profile combination blocks P10 readiness.

P30 - SYSTEM STATUS

Purpose. Provide read-only monitoring of machine, hardware, program and resource facts.

Assumptions / entry conditions.

- Available in SAFE and OPERATE; limited pages available in FAULT.

Sequence of events.

1. Display N01/N02 default page.

2. Allow V11-V16 monitor requests for read-only Nouns.
--

3. Permit KEY REL and priority preemption.
--

4. Return to the prior Program default page or P00.

Exit and recycle behaviour.

- No load Verb is accepted for a read-only fact.
- Monitoring cannot acquire exclusive control of a hardware service.

P31 - PANEL TEST

Purpose. Verify operator-panel input and output hardware without affecting the physical output path.

Assumptions / entry conditions.

- Machine SAFE; authorization INHIBITED.

Sequence of events.

1. Show keypad matrix state and encoder count.
--

2. Require each key once or run a selected subset.
--

3. Exercise OLED patterns.

4. Exercise talkbacks and sounder with bounded patterns.
--

5. Record missing/stuck inputs and output mismatches.

6. Return P00 with result.

Exit and recycle behaviour.

- HARD SAFE and ARM are observed but not simulated.
- FAULT and ENERGY hardware override indications are never suppressed by the test.

P32 - I/O DIAGNOSTICS

Purpose. Observe direct inputs, bus devices and feedback while maintaining safe ownership boundaries.

Assumptions / entry conditions.

- Machine SAFE; release build permits read-only tests only.

Sequence of events.

1. Sample direct inputs and compare against expected idle states.

2. Enumerate required bus devices and addresses.
--

3. Display comparator and feedback status.
--

4. Run permitted bounded feedback tests.
--

5. Record mismatches and recovery results.
--

6. Return P00.

Exit and recycle behaviour.

- No diagnostic can force the timed output path.
- Potentially disruptive tests require P40/service authorization.

P33 - ALARM / RESTART REVIEW

Purpose. Inspect current alarm detail, V05 N09 first/second/latest registers, chronological FRAM history and reset records without changing authorization.

Entry conditions. Available in SAFE and in limited FAULT presentation; outputs remain inhibited.

Sequence.

1. Display N50 current alarm and clearing condition.
2. Permit V05 N09 to show first, second and latest alarm codes.
3. Use N51 cursor selection to browse persistent history.
4. Display N54 reset/recovery record.
5. KEY REL restores the prior nonblocking display.
6. RSET is accepted only when the current descriptor says the cause is clear and resettable.

Exit. Return to the prior Program/default display or P00. Leaving the page does not clear a fault, erase history or alter authorization.

P34 - STORAGE INTEGRITY

Purpose. Verify the integrity of profile, calibration and log storage.

Assumptions / entry conditions.

- Machine SAFE.
- No atomic write is in progress.

Sequence of events.

1. Scan record headers and directories.

2. Verify checksums and revision compatibility.

3. Identify orphaned or incomplete records.

4. Offer only descriptor-authorized repair operations.
--

5. Write an integrity report.
6. Return P00.

Exit and recycle behaviour.

- Repairs are atomic and never discard the last valid profile revision without explicit service authorization.

12. Automatic Sequencing and Background Services

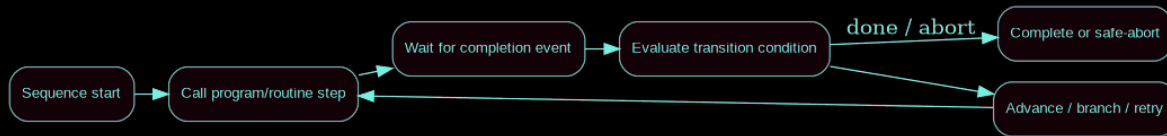


Figure 8. R07 automatic sequencing pattern.

12.1 R07 sequence tables

- Each sequence step identifies a Program or Routine request, completion event, timeout, next-step condition and safe-abort target.
- The sequence controller does not call deep blocking subroutines. It waits through the normal event system.
- Every automatic transition is also legal as a manual transition unless explicitly internal.
- Sequence progress is exposed through N02 and N30.
- A restart invalidates the active sequence and records the interrupted step; recovery returns inhibited.

12.2 Foreground and background ownership

Class	Examples	Rule
Foreground Program	P10, P20, P31	One active major Program.
Foreground Routine	R13 contact test, R15 timed action	One Program-owned modal Routine at a time.
Background service	R02 fact sample, R04 display, R05 panel, R06 alarm	Bounded periodic/event-driven service.
Exclusive hardware service	R15 timed action, storage write	Ownership token prevents simultaneous use.
Priority service	Alarm display and independent cutoff	Can preempt display or hardware request according to policy.

12.3 Optional displays

The CMC allowed optional monitor displays during many Programs without terminating them. ACE adopts the same concept: P30 pages and V11-V16 monitor commands may temporarily own the OLED while the active Program continues. KEY REL or Program prompts restore the appropriate owner.

13. Firmware Mapping and Migration

13.1 Required type and ownership changes

- MachineState contains BOOT, SAFE, STANDBY, OPERATE and FAULT only.
- ProgramCode active_program and ProgramPhase active_phase belong to ProgramExecutive.
- Authorization is a separate AuthorizationState owned by Supervisor/hardware facts.
- CommandExecutive owns staged Program/Verb/Noun/component entry.
- DisplayExecutive owns visible/restoration context; AlarmManager owns alarm records.

13.2 Canonical event families

Family	Required semantic events
Boot/restart	boot complete; restart detected
Safety/facts	fault asserted/cleared; arm/grip/trigger/feedback changed
Program	requested; started; phase changed; completed; aborted
Routine	requested; completed/failed
Command	committed; rejected
Prompt/display	prompt raised; response ENTR/PRO/KEY REL/RSET; display released
Alarm	raised; reset requested/result
Timing	timeout; deadline/cutoff completion

There is no alarm-acknowledgement event. KEY REL is display restoration; RSET is conditional annunciation reset.

13.3 Current-code correction

- Remove the Supervisor transition SAFE + program_request -> PROGRAM.
- Route Program requests to ProgramExecutive.
- After boot completion, enter SAFE and start P00 independently.
- Rename/remove MachineState::program before adding operational Programs.
- Preserve the fixed Event ABI and bounded EventQueue behavior, but do not assume the original capacity is sufficient until measured queue high-water tests pass.
- Dispatch order is explicit: Supervisor, ProgramExecutive, RoutineScheduler, Command/Prompt/Display/Alarm services, then HAL/background work.

13.4 Suggested implementation slices

1. Introduce typed code wrappers and canonical MachineState/AuthorizationState.
2. Add ProgramExecutive with P00 and P30 descriptors.
3. Add V37 command sequence and N01/N02/N03/N09.
4. Add immutable Verb/Noun descriptors and generated compatibility tests.
5. Add DisplayExecutive with one interrupted context and KEY REL tests.
6. Add PromptManager responses for ENTR, PRO, KEY REL and RSET only.
7. Add AlarmManager V05 N09 and N50/N51 behavior.
8. Add HAL back ends for direct pins, three MCP23017 devices, SPI ADC and FRAM.
9. Implement P01/P02/P12/P31/P32/P33/P34 before P10 touches external preparation interfaces.
10. Add P10 as a native phase table plus Routine completion events; do not add executable profile bytecode.

13.5 Test expectations

- Descriptor codes are unique and compatibility tables are exhaustively testable.
- Every writable Noun has a validator; read-only Nouns reject load Verbs.
- Every Program has entry, fallback, timeout and fault-exit policy.
- Every flashing prompt has a finite response/default contract.
- No reset restores authorization or an unfinished action.
- No code path references PROG, ACK, MachineState::program, AlarmAck, ARCVN or a two-expander panel model.
- Host tests cover V37E###E, V05 N09, KEY REL restoration, RSET eligibility and queue overflow/high-water behavior.

14. Verification and Acceptance

14.1 Architectural acceptance

Requirement	Acceptance evidence
Program and MachineState independent	P20/P30 run in SAFE; P10 requests OPERATE separately.
P00 default	successful startup yields SAFE + P00.
V37 sequence frozen	tests cover VERB 3 7 ENTR ## ENTR.
Alarm grammar frozen	V05 N09 = first/second/latest; N50/N51 detail/history.
Prompt responses exact	ENTR, PRO, KEY REL and RSET have distinct tests; no ACK event.
Display restoration bounded	one interrupted context plus pending-owner priority; no unbounded stack.
Hardware contract aligned	4 x 5 keypad, eight talkbacks, three expanders and frozen pin names.
Restart inhibited	no authorization or active request survives reset.
Resources bounded	flash, static SRAM, stack, queue high-water and service latency recorded.

14.2 RevA control-module progression

1. Host-only descriptors, command grammar and state/Program tests.
2. Nano Every build and resource gates.
3. Serial-injected key/event harness.
4. Real 4 x 5 panel, encoder, OLED and eight talkbacks.
5. Three-expander, FRAM and SPI-ADC loopback/simulator.
6. P12 end-to-end dry run.
7. P10 with low-voltage preparation/timed-action interfaces stubbed.
8. Hardware-in-the-loop only after each direct fact and feedback path passes independent verification.

15. Integration Impact and Deferred Decisions

15.1 Superseded identifiers and decisions

Do not implement	Frozen replacement
MachineState::program	MachineState::operate plus independent ProgramCode/ProgramPhase
Supervisor-owned program request	ProgramExecutive validation and lifecycle
PROG key	V37E##E command sequence
ACK key / AlarmAck	KEY REL for display release; RSET after clear; ENTR/PRO prompt contracts
4 x 4 or 5 x 4 panel	4 rows x 5 columns, nineteen functional keys plus spare
SIGN key	separate + and - keys
seven talkbacks	eight including OPR ERR
two expanders	three MCP23017 at 0x20/0x21/0x22
N08/N51 first-second-latest	N09 first-second-latest; N50/N51 detail/history
direct Nano sensor ADC allocation	external SPI ADC and stable logical channel IDs
internal EEPROM profile/log storage	versioned external FRAM records
ARCVM/executable profile	typed profile data plus native Program/Routine sequence tables

15.2 Hardware-manual alignment

NA-ACEHW-001 A.1 contains the same keypad, talkback, pin, bus, expander, ADC and FRAM contracts. Any firmware header generated from these tables must include the master revision and be compared against schematic net names.

15.3 Deferred decisions

- Exact profile field ranges after hardware characterization.
- Whether P21 editing ships in RevA or RevB.
- Number and retention policy of profile/log slots within the frozen FRAM schema.
- Exact alarm severities and automatic-return policy.
- Final production ADC population and transfer functions.
- LGC/AGS review may add sequence conventions but may not change the frozen ownership or response model without a new master revision.

Appendix A. Program/State Compatibility

Program	Permitted MachineState	Authorization rule
P00	SAFE; STANDBY display subset	INHIBITED
P01	BOOT	INHIBITED
P02	BOOT or FAULT recovery	INHIBITED
P06	SAFE to STANDBY	INHIBITED
P10	SAFE entry; OPERATE execution	INHIBITED to PREPARED to ARMED through Supervisor
P11	SAFE entry; OPERATE execution	same as P10, bounded sequence
P12	SAFE	INHIBITED only
P20-P24	SAFE	INHIBITED
P30	SAFE, OPERATE and limited FAULT read-only	never grants authorization
P31-P34	SAFE; P33 limited FAULT	INHIBITED
P40	SAFE with explicit service condition	INHIBITED

P00 is not a FAULT fallback. Fault entry uses P02/P33 or remains faulted until policy permits SAFE.

Appendix B. Event Catalogue

Event	Meaning
EV_BOOT_COMPLETE	Startup invariants passed.
EV_RESTART_DETECTED	Reset cause captured for P02.
EV_FAULT_ASSERTED / EV_FAULT_CLEARED	Authoritative fault fact changed.
EV_PROGRAM_REQUEST	Manual or automatic Program request.
EV_PROGRAM_STARTED	Program entry completed.
EV_PROGRAM_PHASE_CHANGED	Program phase changed.
EV_PROGRAM_COMPLETED	Program completed normally.
EV_PROGRAM_ABORTED	Program followed fault/termination exit.
EV_ROUTINE_REQUEST	Routine request accepted for scheduling.
EV_ROUTINE_COMPLETED / EV_ROUTINE_FAILED	Routine result.
EV_COMMAND_COMMITTED	Complete command committed.
EV_COMMAND_REJECTED	Command rejected with OPR ERR reason.
EV_PROMPT_RAISED	Prompt acquired display ownership.
EV_PROMPT_RESPONSE	ENTR, PRO, KEY REL or RSET response.
EV_DISPLAY_RELEASED	Temporary owner released; restoration evaluated.
EV_ALARM_RAISED	Alarm Manager received a new alarm.
EV_ALARM_RESET_REQUEST / RESULT	Conditional RSET processing.
EV_ARM_CHANGED	Physical ARM input changed.
EV_GRIP_CHANGED	Grip input changed.
EV_TRIGGER_CHANGED	Trigger input changed.
EV_FEEDBACK_CHANGED	Output/trip/direct fact changed.
EV_TIMEOUT	Bounded phase/routine deadline elapsed.

The exact C++ spelling may follow project naming conventions, but these semantics and the absence of EV_ALARM_ACK are frozen.

Appendix C. Source Traceability

Design topic	Source pages	ACE use
DSKY keys/lights	Delco pp. 3-4	distinct PRO, ENTR, KEY REL, RSET and OPR ERR; no PROGRAM key
Program/Routine catalogues	pp. 5-6	separate long-lived Programs and reusable Routines
Verb catalogue	pp. 7-8	display, monitor, load and executive command families
Noun catalogue	pp. 9-14	typed one-to-three component descriptors
Alarm/option/checklist	pp. 15-17	independent namespaces and explicit actions
Display arbitration flags	pp. 23-24	owner/priority/restoration concepts
Program procedures	pp. 40-101	purpose, assumptions, phases, recycle and termination
R07 MINKEY	pp. 102-103	event-driven sequencing above individual Programs

ACE-specific codes are controlled by this A.1 manual and NA-MASTER-001, not by accidental numeric similarity to Apollo.

References

1. Delco Electronics, *Apollo 15 - CM Software, Colossus 3 (Artemis Revision 72)*, CMC section, PDF pages 2-103.
2. NanoArc, NA-MASTER-001 Revision 1.2.
3. NanoArc, NA-CSHID-001 Revision A.1.
4. NanoArc, NA-ACEHW-001 Revision A.1.

DESIGN NOTE: Apollo material is informative design evidence. NanoArc A.1 code tables and master configuration precedence are normative.

Apollo 15 Delco CMC/Colossus Parsed Reference

Scope: PDF pages 2-103 inclusive. PDF page 104 begins the LM Software / Luminary IE / LGC section and is intentionally excluded.

Section map

	PDF pages	Content
	2	CMC title/index
	3-4	CM DSKY lights, display, keyboard, operator semantics
	5	Program catalogue
	6	Routine catalogue
	7-8	Verb catalogue
	9-14	Noun catalogue and formats
	15-16	Alarm catalogue and option codes
	17	Checklist reference codes
	18-28	FLAGWORD assignments
	29-34	IMODES30, IMODES33, OPTMODES, RCSFLAGS, C31FLWORD, DAPDATA1/2
	35-39	CMC input/output channel bit assignments
	40-101	Program operating procedures
	102-103	R07 MINKEY controller procedure
	104	LGC/Luminary section begins - excluded

DSKY model

- Lights: UPLINK ACTY, NO ATT, STBY, KEY REL, OPR ERR, TEMP, GIMBAL LOCK, PROG, RESTART, TRACKER, COMP ACTY.
- Data registers: R1, R2, R3; five digits each with separate sign sections.
- Control registers: two-digit VERB, NOUN, and PROGRAM.
- ENTR executes a Verb/Noun, accepts loaded data, or answers an internal prompt.
- PRO is a context-sensitive proceed response and also participates in standby operation.
- KEY REL arbitrates display ownership between astronaut and internal displays.
- RSET clears indications only after the underlying condition is corrected.

Program catalogue

Phase	Program	Title	Procedure pages
Prelaunch and Service	P00	AGC Idling	40
Prelaunch and Service	P01	Prelaunch or Service - Initialization	40
Prelaunch and Service	P02	Prelaunch or Service - Gyrocompassing	40-41
Prelaunch and Service	P03	Prelaunch or Service - Optical Verification of Gyrocompassing	41-42
Prelaunch and Service	P06	AGC Power Down	42
Prelaunch and Service	P07	System Test	catalogue only
Boost	P11	Earth Orbit Insertion Monitor	43
Boost	P15	TLI Initiate/Cutoff	44
Coast	P20	Universal Tracking	45-48
Coast	P21	Ground Track Determination	48

Phase	Program	Title	Procedure pages
Coast	P22	Orbital Navigation	49-50
Coast	P23	Cislunar Midcourse Navigation	51-53
Coast	P24	Rate Aided Optics Tracking	53-54
Coast	P27	AGC Update	55
Coast	P29	Time-of-Longitude	56
Pre-thrusting	P30	External Delta V	57
Pre-thrusting	P31	CSM Height Adjustment	58-60
Pre-thrusting	P32	Maneuver (HAM) CSM Coelliptic Sequence Initiation (CSI)	61-63
Pre-thrusting	P33	CSM Constant Delta Altitude (CDH)	64-65
Pre-thrusting	P34	CSM Transfer Phase Initiation (TPI)	66-68
Pre-thrusting	P35	Targeting CSM Transfer Phase Midcourse (TPM)	69-70
Pre-thrusting	P36	Targeting CSM Plane Change (PC) Targeting	71-72
Pre-thrusting	P37	Return to Earth	73-74
Thrusting	P40	SPS	75-76
Thrusting	P41	RCS	77-78
Thrusting	P47	Thrust Monitor	78-79
Alignment	P51	IMU Orientation Determination	79-80
Alignment	P52	IMU Realign	81-84
Alignment	P53	Backup IMU Orientation Determination	85
Alignment	P54	Backup IMU Realign	86-88
Entry	P61	Entry - Preparation	89
Entry	P62	Entry - CM/SM Separation and Preentry Maneuver	90
Entry	P63	Entry - Initialization	91
Entry	P64	Entry - Post 0.05G	92
Entry	P65	Entry - Upcontrol	93
Entry	P66	Entry - Ballistic	94
Entry	P67	Entry - Final Phase	95
Pre-thrusting Other Vehicle	P72	LM Coelliptic Sequence Initiation (CSI)	96
Pre-thrusting Other Vehicle	P73	LM Constant Delta Altitude (CDH)	97
Pre-thrusting Other Vehicle	P74	LM Transfer Phase Initiation (TPI)	98
Pre-thrusting Other Vehicle	P75	Targeting LM Transfer Phase (Midcourse)	99
Pre-thrusting Other Vehicle	P76	Targeting LM Target Delta V	100
Pre-thrusting Other Vehicle	P77	CSM Target Delta V	101

Pre-thrusting Other Vehicle	P79	Rendezvous Final Phase	101
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Routine catalogue

Routine	Title
R00	Final Automatic Request Terminate
R01	Erasable and Channel Modification Routine
R02	IMU Status Check
R03	Digital Autopilot Data Load
R05	S-Band Antenna
R07	MINKEY Controller
R21	Rendezvous Tracking Sighting Mark
R22	Rendezvous Tracking Data Processing
R23	Backup Rendezvous Tracking Sighting Mark
R30	Orbit Parameter Display
R31	Rendezvous Parameter Display Routine No. 1
R33	AGC/LGC Clock Synchronization
R34	Rendezvous Parameter Display Routine No. 2
R35	Lunar Landmark Selection
R36	Rendezvous Out-of-Plane Display Routine
R40	SPS Thrust Fail
R41	State Vector Integration (MID to AVE)
R50	Coarse Align
R52	Automatic Optics Positioning
R53	Sighting Mark
R54	Sighting Mark Display
R55	Gyro Torquing
R56	Alternate LOS Sighting Mark
R57	Optics Calibration
R60	Attitude Maneuver
R61	Tracking Attitude
R62	Crew-Defined Maneuver
R63	Rendezvous Final Attitude
R67	Universal Tracking Rotation

Verb catalogue

	Verb	Class	Meaning
	V00	regular	Not in use
	V01	regular	Display octal component 1 in R1
	V02	regular	Display octal component 2 in R1
	V03	regular	Display octal component 3 in R1
	V04	regular	Display octal components 1, 2 in R1, R2
	V05	regular	Display octal components 1, 2, 3 in R1, R2, R3
	V06	regular	Display decimal in R1 or R1, R2 or R1, R2, R3
	V07	regular	Display DP decimal in R1, R2 (test only)
	V08	regular	Spare
	V09	regular	Spare
	V10	regular	Spare
	V11	regular	Monitor octal component 1 in R1

	Verb	Class	Meaning
	V12	regular	Monitor octal component 2 in R1
	V13	regular	Monitor octal component 3 in R1
	V14	regular	Monitor octal components 1, 2 in R1, R2
	V15	regular	Monitor octal components 1, 2, 3 in R1, R2, R3
	V16	regular	Monitor decimal in R1 or R1, R2 or R1, R2, R3
	V17	regular	Monitor DP decimal in R1, R2 (test only)
	V18	regular	Spare
	V19	regular	Spare
	V20	regular	Spare
	V21	regular	Load component 1 into R1
	V22	regular	Load component 2 into R2
	V23	regular	Load component 3 into R3
	V24	regular	Load components 1, 2 into R1, R2
	V25	regular	Load components 1, 2, 3 into R1, R2, R3
	V26	regular	Spare
	V27	regular	Display fixed memory
	V28	regular	Spare
	V29	regular	Spare
	V30	regular	Request EXECUTIVE
	V31	regular	Request WAITLIST
	V32	regular	Recycle program
	V33	regular	Proceed without DSKY inputs
	V34	regular	Terminate function
	V35	regular	Test lights
	V36	regular	Request FRESH START
	V37	regular	Change program (major mode)
	V38	regular	Spare
	V39	regular	Spare
	V40	extended	Zero ICDU
	V41	extended	Coarse align CDUs (specify N20 or N91)
	V42	extended	Pulse torque gyros
	V43	extended	Load IMU attitude error needles (test only)
	V44	extended	Set surface flag
	V45	extended	Reset surface flag
	V46	extended	Establish G & N autopilot control
	V47	extended	Move LM state vector into CM state vector
	V48	extended	Request DAP Data Load routine (R03)
	V49	extended	Start automatic attitude maneuver
	V50	extended	Please perform
	V51	extended	Please mark
	V52	extended	Mark on offset landing site
	V53	extended	Please perform COAS mark
	V54	extended	Request Rendezvous Backup Sighting Mark routine (R23)
	V55	extended	Increment AGC time (decimal)
	V56	extended	Terminate tracking (P20)

	Verb	Class	Meaning
	V57	extended	Request display of full track flag (FULTKFLAG)
	V58	extended	Reset Stick flag and set V50 N18 flag
	V59	extended	Please calibrate
	V60	extended	Set astronaut total attitude (N17) to present attitude
	V61	extended	Display DAP following attitude errors (Mode 1)
	V62	extended	Display total attitude errors with respect to Noun 22 (Mode 2)
	V63	extended	Display total astronaut attitude error with respect to Noun 17 (Mode 3)
	V64	extended	Request S-Band Antenna routine (R05)
	V65	extended	Optical verification of prelaunch alignment
	V66	extended	Vehicles are attached; move this vehicle state vector to other vehicle
	V67	extended	Start W-matrix RMS error display
	V68	extended	Spare
	V69	extended	Cause RESTART
	V70	extended	Update liftoff time (P27)
	V71	extended	Start AGC update; block address (P27)
	V72	extended	Start AGC update; single address (P27)
	V73	extended	Start AGC update; AGC time (P27)
	V74	extended	Initialize erasable dump via DOWNLINK
	V75	extended	Backup liftoff
	V76	extended	Spare
	V77	extended	Spare
	V78	extended	Update prelaunch azimuth
	V79	extended	Spare
	V80	extended	Enable LM state vector update
	V81	extended	Enable CSM state vector update
	V82	extended	Request Orbit Parameter display (R30)
	V83	extended	Request Rendezvous Parameter display No. 1 (R31)
	V84	extended	Spare
	V85	extended	Request Rendezvous Parameter display No. 2 (R34)
	V86	extended	Reject Rendezvous Backup Sighting Mark
	V87	extended	Set VHF Range flag
	V88	extended	Reset VHF Range flag
	V89	extended	Request Rendezvous Final Attitude maneuver (R63)
	V90	extended	Request Out-of-Plane Rendezvous display (R36)
	V91	extended	Display BANKSUM
	V92	extended	Spare

	Verb	Class	Meaning
	V93	extended	Enable W-matrix initialization
	V94	extended	Perform Cislunar Attitude maneuver
	V95	extended	Spare
	V96	extended	Terminate integration and go to P00
	V97	extended	Please perform engine-fail (R40)
	V98	extended	Spare
	V99	extended	Please enable engine ignition

Noun catalogue

Noun	Name	Components	Formats	Load locked
N00	Not in use			
N01	Specify address (fractional)	component 1component 2component 3	.XXXXX frac- tional.XXXXX frac- tional.XXXXX fractional XXXXX.	
N02	Specify address (whole)	component 1component 2component 3	integerXXXXX. integerXXXXX. integer XXX.XX	
N03	Specify address (degree)	component 1component 2component 3	degXXX.XX degXXX.XX deg	
N04	Spare			
N05	Angular error/difference	value	XXX.XX deg	
N06	Option code	Option code IDOption code	OctalOctal	
N07	FLAGWORD operator	ECADRBIT IDAction	OctalOctalOctal	
N08	Alarm data	ADRESBBANKERCOUNT	OctalOctalOctal	
N09	Alarm codes	FirstSecondLast	OctalOctalOctal	
N10	Channel to be specified	channel	Octal	
N11	TIG of CSI	hoursminutesseconds	00XXX. h000XX. min0XX.XX s	
N12	Option code (extended verbs only)	Option code IDOption code	OctalOctal	
N13	TIG of CDH	hoursminutesseconds	00XXX. h000XX. min0XX.XX s	
N14	Specified inertial velocity at TLI cutoff (VI C/O)	velocity	XXXXX. ft/s	
N15	Increment address	address	Octal	
N16	Time of event (used by extended verbs only)	hoursminutesseconds	00XXX. h000XX. min0XX.XX s	
N17	Astronaut total attitude	RPY	XXX.XX degXXX.XX degXXX.XX deg	

	Noun	Name	Components	Formats	Load locked
	N18	Desired automaneuver FDAI ball angles	RPY	XXX.XX degXXX.XX degXXX.XX deg	
	N19	Spare			
	N20	Present ICDU angles	R (OG)P (IG)Y (MG)	XXX.XX degXXX.XX degXXX.XX deg	
	N21	PIPAs	XYZ	XXXXX. pulsesXXXXX. pulsesXXXXX. pulses	
	N22	Desired ICDU angles	R (OG)P (IG)Y (MG)	XXX.XX degXXX.XX degXXX.XX deg	
	N23	Spare			
	N24	Delta time for AGC clock	hoursminutesseconds	000XXX. h000XX. min0XX.XX s	
	N25	CHECKLIST (used with V50)	checklist code	XXXXX.	
	N26	PRIO/DELAY, ADRES, BBCON	PRIO/DELAYADRESBBCON	SPBACONhOctal	
	N27	Self-test on/off switch	switch	XXXXX.	
	N28	Spare			
	N29	XSM launch azimuth	azimuth	XXX.XX deg	
	N30	Target codes	code 1code 2code 3	XXXXX.XXXXXX.XXXXXX.	
	N31	Time of W-matrix initialization	hoursminutesseconds	000XXX. h000XX. min0XX.XX s	
	N32	Time from perigee	hoursminutesseconds	000XXX. h000XX. min0XX.XX s	
	N33	Time of ignition (GETI)	hoursminutesseconds	000XXX. h000XX. min0XX.XX s	
	N34	Time of event	hoursminutesseconds	000XXX. h000XX. min0XX.XX s	
	N35	Time from event	hoursminutesseconds	000XXX. h000XX. min0XX.XX s	
	N36	Time of AGC clock	hoursminutesseconds	000XXX. h000XX. min0XX.XX s	
	N37	Time of ignition (TPI)	hoursminutesseconds	000XXX. h000XX. min0XX.XX s	
	N38	Time of state being integrated	hoursminutesseconds	000XXX. h000XX. min0XX.XX s	
	N39	Delta time for transfer	hoursminutesseconds	000XXX. h000XX. min0XX.XX s	
	N40	Time from ignition/cutoff (TFI/TFC); VG; Delta V accumulated	TFI/TFCVGDelta V accumulated	XX b XX min/sXXXXX.X ft/sXXXXX.X ft/s	yes
	N41	Target	AzimuthElevation	XXX.XX degXX.XXX deg	

Noun	Name	Components	Formats	Load locked
N42	Apocenter altitude; Pericenter altitude; Delta V required	Apocenter altitude Pericenter altitude Delta V required	XXXX.X nmiXXXX.X nmiXXXX.X ft/s	yes
N43	Latitude; Longitude; Altitude	Latitude Longitude	XXXX.X deg (+ north) XXXX.XX deg (+ east) XXXX.X nmi	
N44	Apocenter altitude; Pericenter altitude; TFF	Apocenter altitude Pericenter altitude TFF	XXXX.X nmiXXXX.X nmiXX b XX min/s	yes
N45	Marks; Time from ignition of next burn; Middle gimbal angle	Marks (VHF/optics) Time from ignition of next burn Middle gimbal angle	XX b XX marksXX b XX min/s XXXX.XX deg	yes
N46	DAP configuration	word 1 word 2	Octal Octal	
N47	CSM and LM weight	CSM weight LM weight	XXXXX. lbsXXXXX. lbs	
N48	Gimbal trim	Gimbal pitch trim Gimbal yaw trim	XXX.XX degXXX.XX deg	
N49	State-vector update delta	Delta R Delta V VHF or optics code	XXXX.X nmiXXXX.X ft/s0000X.	
N50	Splash error; Perigee; TFF	Splash error- Perigee TFF	XXXX.X nmiXXXX.X nmiXX b XX min/s	yes
N51	S-band antenna angles	RHOGAMMA	XXX.XX degXXX.XX deg	
N52	Central angle of active vehicle	angle	XXX.XX deg	
N53	Range; Range rate; Phi	Range Range rate Phi	XXX.XX nmiXXXX.X ft/sXXX.XX deg	
N54	Range; Range rate; Theta	Range Range rate Theta	XXX.XX nmiXXXX.X ft/sXXX.XX deg	
N55	Perigee code; Elevation angle; Central angle of passive vehicle	Perigee code Elevation angle Central angle of passive vehicle	0000X.XXX.XX degXXX.XX deg	
N56	Reentry angle; Delta V	Reentry angle Delta V	XXX.XX degXXXXX. ft/s	
N57	Spare			
N58	Pericenter altitude (post TPI); Delta V (TPI); Delta V (TPF)	Pericenter altitude (post TPI) Delta V (TPI) Delta V (TPF)	XXXX.X nmiXXXX.X ft/sXXXX.X ft/s	

Noun	Name	Components	Formats	Load locked
N59	Delta V LOS	Delta V LOS 1Delta V LOS 2Delta V LOS 3	XXXX.X ft/sXXXX.X ft/sXXXX.X ft/s	
N60	GMAX; VPRED; GAMMA EI	GMAXVPREDGAM EI	XXXX.XX gXXXXX. ft/sXXX.XX deg (+ above)	
N61	Impact	LatitudeLongitude up/down	XXXX.XX deg (+ north)XXX.XX deg (+ east)+/- 00001	
N62	Inertial velocity magnitude; Altitude rate; Altitude above pad radius	Inertial velocity magnitudeAlti- tude rateAltitude above pad radius	XXXXX. ft/sXXXXX. ft/sXXXX.X nmi	
N63	Range from EI altitude to splash; Predicted inertial velocity; Time from EI altitude	Range from EI altitude to splashPre- dicted inertial velocityTime from EI altitude	XXXX.X nmiXXXXX. ft/sXX b XX min/s	yes
N64	Drag acceleration; Inertial velocity; Range to splash	Drag accelera- tionInertial velocityRange to splash	XXX.XX gXXXXX. ft/sXXXX.X nmi (+ is overshoot)	
N65	Sampled AGC time (fetched in interrupt)	hoursminutesseconds	000XXX. h000XX. min0XX.XX s	
N66	Commanded bank angle; Crossrange error; Downrange error	Commanded bank angle- Crossrange errorDown- range error	XXX.XX degXXXXX.X nmi (+ south)XXXXX.X nmi (+ overshoot)	
N67	Range to target; Present latitude; Present longitude	Range to targetPresent latitudePresent longitude	XXXXX.X nmi (+ over- shoot)XXX.XX deg (+ north)XXX.XX deg (+ east)	
N68	Commanded bank angle; Inertial velocity; Altitude rate	Commanded bank angleInertial velocityAltitude rate	XXX.XX degXXXXX. ft/sXXXXX. ft/s	
N69	Commanded bank angle; Drag level; Exit velocity	Commanded bank angleDrag levelExit velocity	XXX.XX degXXX.XX gXXXXX. ft/s	
N70	Celestial body code (before mark)	Celestial body codeLandmark dataHorizon data	OctalOctalOctal	

Noun	Name	Components	Formats	Load locked
N71	Celestial body code (after mark)	Celestial body codeLandmark dataHorizon data	OctalOctalOctal	
N72	Spare			
N73	Altitude; Velocity; Flight path angle	AltitudeVelocityFlight path angle	XXXXXB. nmiXXXXX. ft/sXXX.XX deg	
N74	Commanded bank angle; Inertial velocity; Drag acceleration	Commanded bank angleInertial velocityDrag acceleration	XXX.XX degXXXXX. ft/sXXX.XX g	
N75	Delta altitude and timing	Delta altitude (CDH)Delta time (CDH-CSI or TPI-CDH)Delta time (TPI-CDH or TPI-NOMTPI)	XXXX.X nmiXX b XX min/sXX b XX min/s	yes
N76	Spare			
N77	Spare			
N78	GAMMA; RHO; OMICRON	GAMMARHOOMICRON	XXXXX degXXX.XX degXXX.XX deg X.XXXX deg/sXXX.XX deg	
N79	P20 rotation	P20 rotation rateP20 deadband	XX b XX min/sXXXXX. ft/sXXXXX. ft/s	
N80	Time from ignition/cutoff; Velocity to be gained; Delta V accumulated	Time from ignition/cutoffVelocity to be gainedDelta V accumulated		yes
N81	Delta V in local vertical coordinates	Delta VX (LV)Delta VY (LV)Delta VZ (LV)	XXXX.X ft/sXXXX.X ft/sXXXX.X ft/s	
N82	Delta V in local vertical coordinates (second vector)	Delta VX (LV)Delta VY (LV)Delta VZ (LV)	XXXX.X ft/sXXXX.X ft/sXXXX.X ft/s	
N83	Delta V in body coordinates	Delta VX (body)Delta VY (body)Delta VZ (body)	XXXX.X ft/sXXXX.X ft/sXXXX.X ft/s	
N84	Delta V in other vehicle local vertical coordinates	Delta VX (LV of other vehicle)Delta VY (LV of other vehicle)Delta VZ (LV of other vehicle)	XXXX.X ft/sXXXX.X ft/sXXXX.X ft/s	
N85	Velocity-to-be-gained in body coordinates	VGX (body)VGY (body)VGZ (body)	XXXX.X ft/sXXXX.X ft/sXXXX.X ft/s	

Noun	Name	Components	Formats	Load locked
N86	Delta V in local vertical coordinates	Delta VX (LV)Delta VY (LV)Delta VZ (LV)	XXXXX. ft/sXXXXX. ft/sXXXXX. ft/s	
N87	Mark data	Shaft angleTrunnion angle	XXX.XX degXX.XXX deg	
N88	Celestial body unit vector	XYZ	.XXXXX.XXXXXX.XXXXXX	
N89	Landmark coordinates	Landmark lati- tudeLandmark longi- tude/2Landmark altitude	XX.XXX deg (+ north)XX.XXX deg (+ east)XXX.XX nmi	
N90	Rendezvous out-of-plane parameters	Y (Active)YDOT (Active)YDOT (Passive)	XXX.XX nmiXXXXX.X ft/sXXXXX.X ft/s	
N91	Present optics angles	ShaftTrunnion	XXX.XX degXX.XXX deg	
N92	New optics angles	ShaftTrunnion	XXX.XX degXX.XXX deg	
N93	Delta gyro angles	XYZ	XX.XXX degXX.XXX degXX.XXX deg	
N94	Alternate LOS	Shaft angleTrunnion angle	XXX.XX degXX.XXX deg	
N95	P15 timing and velocity	Time from ignition (cutoff)VG (P15)VI (P15)	XXbXX min/sXXXXX. ft/sXXXXX. ft/s	
N96	Out-of-plane state	Y (CSM)YDOT (CSM)YDOT (LM)	XXX.XX nmiXXXXX.X ft/sXXXXX.X ft/s	
N97	System test inputs	input 1input 2input 3	XXXXX.XXXXXX.XXXXXX.	
N98	System test results and input	result 1result 2input	XXXXX.- XXXXXXXXXXXXX.	
N99	RMS errors	RMS in positionRMS in velocityRMS option code	XXXXX. ftXXXXX.X ft/sXXXXX.	

Alarm catalogue

Code	Purpose	Set by	Class
00110	No mark since last mark reject	SXTMARK	normal
00113	No inbits (Channel 16)	SXTMARK	normal
00114	Mark made but not desired	SXTMARK	normal
00115	Optics torque request with switch not at CMC	Extended verb optics CDU	normal

Code	Purpose	Set by	Class
00116	Optics switch altered before 15-second ZERO time elapsed	T4RUPT	normal
00117	Optics torque request with optics not available	Extended verb optics CDU	normal
00120	Optics torque request with optics not ZEROED	T4RUPT	normal
00121	Optics CDUs no good at time of mark	SXTMARK	normal
00205	Bad PIPA reading	SERVICER	normal
00206	Zero encode not allowed with coarse align + gimbal lock	IMU mode switch	normal
00207	ISS turn-on request not present for 90 seconds	T4RUPT	normal
00210	IMU not operating	IMU mode switch, IMU-2, R02, P51	normal
00211	Coarse align error-drive > 2 degrees	IMU mode switch	normal
00212	PIPA fail but PIPA is not being used	IMU mode switch, T4RUPT	normal
00213	IMU not operating with turn-on request	T4RUPT	normal
00214	Program using IMU when turned off	T4RUPT	normal
00217	Bad return from Stall routines	CURTAINS	normal
00220	IMU not aligned (no REFSMMAT)	R02, P51	normal
00401	Desired gimbal angles yield Gimbal Lock	Fine Align, IMU-2	normal
00402	Second MINKEY pulse torque must be done	P52	normal
00404	Target out of view (trunnion angle > 90 degrees)	R52	auto_display_response_require
00405	Two stars not available	P52, P54	auto_display_response_require
00406	Rendezvous navigation not operating	R21, R23	normal
00421	W-Matrix overflow	INTEGRV	normal
00600	Imaginary roots on first iteration	P32, P72	auto_display_response_require
00601	Perigee altitude after CSI < 85 nmi earth orbit / 35,000 ft moon orbit	P32, P72	auto_display_response_require
00602	Perigee altitude after CDH < 85 nmi earth orbit / 35,000 ft moon orbit	P32, P72	auto_display_response_require
00603	CSI to CDH time < 10 minutes	P32, P33, P72, P73	auto_display_response_require
00604	CDH to TPI time < 10 minutes	P32, P72	auto_display_response_require

	Code	Purpose	Set by	Class
	00605	Number of iterations exceeds loop maximum	P32, P72, P37	auto_display_response_require
	00606	DV exceeds maximum	P32, P72	auto_display_response_require
	00611	No TIG for given elevation angle	P34, P74	auto_display_response_require
	00612	State vector in wrong sphere of influence	P37	auto_display_response_require
	00613	Reentry angle out of limits	P37	auto_display_response_require
	00777	PIPA fail caused ISS warning	T4RUPT	normal
	01102	AGC self-test error	SELF-CHECK	normal
	01105	Downlink too fast	T4RUPT	normal
	01106	Uplink too fast	T4RUPT	normal
	01107	Phase table failure; assume erasable memory is destroyed	RESTART	normal
	01301	ARCSIN-ARCCOS argument too large	INTERPRETER	normal
	01407	VG increasing	S40.8	normal
	01426	IMU unsatisfactory	P61, P62	auto_display_no_response
	01427	IMU reversed	P61, P62	auto_display_no_response
	01520	V37 request not permitted at this time	V37	normal
	01600	Overflow in Drift Test	Optical Prealignment Calibration	normal
	01601	Bad IMU torque	Optical Prealignment Calibration	normal
	01703	Insufficient time for integration; TIG was slipped	R41	normal
	03777	ICDU fail caused the ISS warning	T4RUPT	normal
	04777	ICDU, PIPA fails caused the ISS warning	T4RUPT	normal
	07777	IMU fail caused the ISS warning	T4RUPT	normal
	10777	IMU, PIPA fails caused the ISS warning	T4RUPT	normal
	13777	IMU, ICDU fails caused the ISS warning	T4RUPT	normal
	14777	IMU, ICDU, PIPA fails caused the ISS warning	T4RUPT	normal
	20430	Integration abort due to subsurface state vector	All calls to integration	abort_2xxxx
	20607	No solution from Time-Theta or Time-Radius	TIMETHET, TIMERAD	abort_2xxxx
	20610	Lambda less than unity	P37	abort_2xxxx
	21204	Negative or zero WAITLIST call	WAITLIST	abort_2xxxx
	21206	Second job attempts to go to sleep via Keyboard and Display program	PINBALL	abort_2xxxx

	Code	Purpose	Set by	Class
	21210	Two programs using device at same time	IMU Mode Switch	abort_2xxxx
	21302	SORT called with negative argument	INTERPRETER	abort_2xxxx
	21501	Keyboard and Display alarm during internal use (NVSUB)	PINBALL	abort_2xxxx
	21502	Illegal flashing display	GOPLAY	abort_2xxxx
	21521	P01 illegally selected	P01	abort_2xxxx
	31104	Delay routine busy	EXECUTIVE	bailout_3xxxx
	31201	Executive overflow - no VAC areas available	EXECUTIVE	bailout_3xxxx
	31202	Executive overflow - no core sets available	EXECUTIVE	bailout_3xxxx
	31203	WAITLIST overflow - too many tasks	WAITLIST	bailout_3xxxx
	31211	Illegal interrupt of Extended Verb	SXTMARK, P23	bailout_3xxxx

Option codes

	Code	Purpose	Choices	Programs
	00001	Specify IMU orientation	1 = preferred2 = nominal3 = REFSMMAT4 = landing site	P50 series
	00002	Specify vehicle	1 = this vehicle2 = other vehicle	P21, R30
	00003	Specify tracking attitude	1 = preferred2 = +X-axis	R63
	00004	Specify FULTKFLAG setting	0 = Full, VHF and optics1 = Partial, VHF or optics	P20
	00007	Specify propulsion system	1 = SPS2 = RCS	P37
	00024	Specify P20 mode	0 = Rendezvous (VECPOINT)1 = Celestial body (VECPOINT)2 = Rotate4 = Rendezvous (3-axis)5 = Celestial body (3-axis)	P20

Checklist reference codes

Code	Action
00013	Perform coarse alignment
00014	Key in fine alignment option
00015	Perform celestial body acquisition
00016	Key in terminate mark sequence
00017	Perform MINKEY rendezvous sequence
00020	Perform MINKEY PC pulse torquing
00041	Switch CM/SM separation to UP
00062	Key in AGC power down
00202	Perform GNCS automatic maneuver

Code	Action
00204	Perform SPS gimbal trim

Flagword and channel material

- PDF pages 18-28: FLAGWORD 0-11 assignments and alphabetical index.
- PDF pages 29-34: IMODES30, IMODES33, OPTMODES, RCSFLAGS, C31FLWORD, DAPDATA1, and DAPDATR2.
- PDF pages 35-39: input/output channel assignments, including DSKY lamp outputs, keycode inputs, discrete inputs, and restart monitor bits.
- The complete extracted text for these pages is present in the structured JSON and raw transcript.

Program procedure index

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Files in this parse set

- A15Delco_CMC_Parsed_Reference.md - normalized catalogues and section map.
- A15Delco_CMC_Structured.json - normalized tables, raw page text, and program procedure blocks.
- A15Delco_CMC_Program_Procedures.md - program procedures grouped by program/routine.
- A15Delco_CMC_Transcript.txt - page-by-page extracted CMC text.

Quality and usage notes

- The catalogue tables were checked against rendered scans rather than trusted blindly from OCR.
- The long program procedures remain close to the original scan text so we can derive ACE flows without silently inventing missing steps.
- This parse does not include the LGC/Luminary section beginning on PDF page 104.

Apollo 15 Delco - CMC/Colossus Program Procedures

Parsed scope: PDF pages 40-103. The LGC/Luminary section begins at PDF page 104.
This is a lightly cleaned OCR transcription organized by program. Ambiguous characters should be checked against the scan.

P00 - AGC Idling

Source PDF pages: 40

--- PDF page 40 ---

CM-39

P00--CMC IDLING PROGRAM

Purpose:

- 1. To maintain the CMC in a condition of readiness for entry into other programs.
- 2. To update the CSM and LM state vectors every four time steps.

Assumptions:

- 1. This program is automatically selected by V96E, which may be done during any program. State vector integration is permanently inhibited following V96E. Normal integration functions will resume after selection of any program or extended version of P00 integration will resume when P00 is reselected. Usage of V96 can cause incorrect W-matrix and state vector synchronization.
- 2. Program changes are inhibited during integration periods and program alarm 1820, will occur if a change is attempted when inhibited.

Sequence of Events:

V37E00E
V06N38E

Optional Display		
V06N38.	Time of State Vector Being Integrated	00XXX h 000XX min 0XX.XX s

P01--PRELAUNCH OR SERVICE--INITIALIZATION PROGRAM

Purpose:

- 1. To initialize the platform for the prelaunch programs.
- 2. To provide an initial stable member orientation for Gyrocompassing (P02).

Assumptions:

- 1. Erasable locations have been properly initialized. (Azimuth, +1; Latitude, +1; LAU NCHAZ, +1; IMU compensation parameters).

Sequence of Events:

V37E01E

No Att Light - ON, then OFF. Initializes the system and coarse aligns the platform to the desired orientation.
AGC advances to P02.

P002--PRELAUNCH OR SERVICE--GY ROCOMPASSING

PROGRAM

Purpose:

1. To provide the proper stable member orientation for launch.

Assumptions:

1. This program may be interrupted to perform the Prelaunch or Service--Optical Verification of Gyrocompassing program (P03).

2. V75 will be keyed in and displayed during this program to permit crew backup of the liftoff discrete.

3. The program is automatically selected by the Initialization program (P01).

4. This program has the capability (via V78E) to change the launch azimuth of the stable member while gyrocompassing.

P01 - Prelaunch or Service - Initialization

Source PDF pages: 40

--- PDF page 40 ---

CM-39

P00--CMC IDLING PROGRAM

Purpose:

1. To maintain the CMC in a condition of readiness for entry into other programs.

2. To update the CSM and LM state vectors every four time steps.

Assumptions:

1. This program is automatically selected by V96E, which may be done during any program. State vector integration is permanently inhibited following V96E. Normal integration functions will resume after selection of any program or extended version of P00 integration will resume when P00 is reselected. Usage of V96 can cause incorrect W-matrix and state vector synchronization.

2. Program changes are inhibited during integration periods and program alarm 1820, will occur if a change is attempted when inhibited.

Sequence of Events:

V37E00E
V06N38E

Optional Display		
V06N38.	Time of State Vector Being Integrated	00XXX h 000XX min 0XX.XX s

P01--PRELAUNCH OR SERVICE--INITIALIZATION PROGRAM

Purpose:

1. To initialize the platform for the prelaunch programs.
2. To provide an initial stable member orientation for Gyrocompassing (P02).

Assumptions:

1. Erasable locations have been properly initialized. (Azimuth, +1; Latitude, +1; LAU NCHAZ, +1; IMU compensation parameters).

Sequence of Events:

V37E01E

No Att Light – ON, then OFF. Initializes the system and coarse aligns the platform to the desired orientation. AGC advances to P02.

P002–PRELAUNCH OR SERVICE–GYROCOMPASSING

PROGRAM

Purpose:

1. To provide the proper stable member orientation for launch.

Assumptions:

1. This program may be interrupted to perform the Prelaunch or Service–Optical Verification of Gyrocompassing program (P03).
2. V75 will be keyed in and displayed during this program to permit crew backup of the liftoff discrete.
3. The program is automatically selected by the Initialization program (P01).
4. This program has the capability (via V78E) to change the launch azimuth of the stable member while gyrocompassing.

P02 - Prelaunch or Service - Gyrocompassing

Source PDF pages: 40-41

--- PDF page 40 ---

CM-39

P00--CMC IDLING PROGRAM

Purpose:

1. To maintain the CMC in a condition of readiness for entry into other programs.
2. To update the CSM and LM state vectors every four time steps.

Assumptions:

1. This program is automatically selected by V96E, which may be done during any program. State vector integration is permanently inhibited following V96E. Normal integration functions will resume after selection of any program or extended version of P00 integration will resume when P00 is reselected. Usage of V96 can cause incorrect W-matrix and state vector synchronization.
2. Program changes are inhibited during integration periods and program alarm 1820,

will occur if a change is attempted when inhibited.

Sequence of Events:

V37E00E

V06N38E

Optional Display

V06N38.

Time of State Vector Being Integrated

00XXX h

000XX min

0XX.XX s

P01-PRELAUNCH OR SERVICE-INITIALIZATION PROGRAM

Purpose:

1. To initialize the platform for the prelaunch programs.
2. To provide an initial stable member orientation for Gyrocompassing (P02).

Assumptions:

1. Erasable locations have been properly initialized. (Azimuth, +1; Latitude, +1; LAU NCHAZ, +1; IMU compensation parameters).

Sequence of Events:

V37E01E

No Att Light - ON, then OFF. Initializes the system and coarse aligns the platform to the desired orientation. AGC advances to P02.

P002-PRELAUNCH OR SERVICE-GYROCOMPASSING

PROGRAM

Purpose:

1. To provide the proper stable member orientation for launch.

Assumptions:

1. This program may be interrupted to perform the Prelaunch or Service-Optical Verification of Gyrocompassing program (P03).
2. V75 will be keyed in and displayed during this program to permit crew backup of the liftoff discrete.
3. The program is automatically selected by the Initialization program (P01).
4. This program has the capability (via V78E) to change the launch azimuth of the stable member while gyrocompassing.

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CM-40

P02 (continued)

Sequence of Events:

P02 entered automatically from P01.

Vertical erect for 640 seconds, then gyrocompass.

V78E Optional entry if launch azimuth change is desired.

Flashing XSM Launch Azimuth

XXX.XX deg

V06N29

V21E. Enter new launch azimuth.

Vertical erect for 320 seconds, then gyrocompass.

V75E Optional at Liftoff if automatic Liftoff discrete is not received.

AGC advances to P11 at liftoff.

P03---PRELAUNCH OR SERVICE--OPTICAL VERIFICATION OF GYROCOMPASSING

Purpose:

1. To provide an optical check for verification of alignment of the stable member during gyrocompassing prior to launch.

Assumptions:

1. The astronaut has zeroed the optics just prior to program (P03) selection.
2. A minimum of 45 minutes between V78E and P03 (V65E) assures proper damping of transients.
3. In order to prematurely terminate this program and return to P02 the astronaut may key in V34E on anyflashingdisplay.

Sequence of Events:

Zero Optics for 15 seconds.

Vese

P03displayed.

V0SN30	Target ID (R3)	00001
Flashing	Target Azimuth	XXX.XX deg
V06N41	Target Elevation	XX.XXX deg

Target 1 coordinates.

V24E. Change azimuth and elevation if desired.

PRO

V0SN30	Target ID (R3)	00002
Flashing	Target Azimuth	XXX.XX deg
V06N41	Target Elevation	XX.XXX deg

Target 2 coordinates.

V24E. Change azimuth and elevation if desired.

Optics Mode -- CMC.

PRO

CMCdrives optics LOS to Target 1.

Flashing

v51

Optics to Manual -- Mark on Target1.

Flashing	Checklist Code	00016
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VS50N25

Request terminate Mark sequence

P03 - Prelaunch or Service - Optical Verification of Gyrocompassing

Source PDF pages: 41-42

--- PDF page 41 ---

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P02 (continued)

Sequence of Events:

P02entered automatically from P01.

Vertical erect for 640 seconds, then gyrocompass.

V78E Optionalentry if launch azimuth changeis desired.

Flashing	XSM Launch Azimuth	XXX.XX deg
----------	--------------------	------------

V06N29

V21E. Enter new launch azimuth.

Vertical erect for 320 seconds, then gyrocompass.

V75E Optional at Liftoff if automatic Liftoff discrete is not received.

AGC advances to P11 at liftoff.

P03---PRELAUNCH OR SERVICE--OPTICAL VERIFICATION
OF GYROCOMPASSING

Purpose:

1. To provide an optical check for verification of alignment of the stable member during gyrocompassing prior to launch.

Assumptions:

1. The astronaut has zeroed the optics just prior to program (P03) selection.
2. A minimum of 45 minutes between V78E and P03 (V65E) assures proper damping of transients.
3. In order to prematurely terminate this program and return to P02 the astronaut may key in V34E on anyflashingdisplay.

Sequence of Events:

Zero Optics for 15 seconds.

Vese

P03displayed.

V0SN30	Target ID (R3)	00001
Flashing	Target Azimuth	XXX.XX deg
V06N41	Target Elevation	XX.XXX deg

Target 1 coordinates.

V24E. Change azimuth and elevation if desired.

PRO

V0SN30	Target ID (R3)	00002
Flashing	Target Azimuth	XXX.XX deg
V06N41	Target Elevation	XX.XXX deg

Target 2 coordinates.

V24E. Change azimuth and elevation if desired.

Optics Mode -- CMC.

PRO

CMCdrives optics LOS to Target 1.

Flashing

v51

Optics to Manual -- Mark on Target1.

Flashing	Checklist Code	00016
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VS50N25

Request terminate Mark sequence

--- PDF page 42 ---

CM-41

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i
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}

```

P03 (continued)

MARK REJECT

(If mark was unsatisfactory), and

recycle to Flashing V51.

PRO (if mark was satisfactory), and continue.

CMC drives optics LOS to Target 2
 Flashing
 v51
 Optics to Manual – Mark on Target 2.
 Flashing
 VS50N25 Checklist Code 00016
 Terminate mark sequence.
 MARK REJECT (If mark was unsatisfactory), and recycle to previous Flashing V51.
 PRO (If mark was satisfactory), and continue.
 Flashing Alignment Error
 V06N93 X XX.XXX d
 In Delta Gyro Angles Y XX.XXX deg
 Displays Ysq and Xgy leveling error and Xsyy azimuth error. Z XX.XXX deg
 V24E to zero Y and leveling errors.
 PRO TorquesZ gyro to eliminate azimuth error.
 V34E Terminates optical verification and returns to P02

P06—CMC POWER DOWN PROGRAM

M

Purpose:

1. To transfer the CMC from the operative to the standby condition.

Assumptions:

1. If the computer power is switched off, the AGC Update program (P2) would be done to update the state vector and computer clock time.
2. The AGC is capable of maintaining an accurate value of ground for only 23 hours when in the standby condition. If the AGC is not brought out of the standby condition to the running condition at least once within 23 hours, the AGC value of GET must be updated.
3. Once the program has been selected, the AGC must be Put in Standby. When POG appears, the AGC will not hold a new (V34E), or an ENTER in response to the request (V37EXXE), a termination by,

Sequence of Events:

V37E06E

Flashing Checklist Code
 VS50N25 00062
 Power down AGC.
 If IMU poweroff desired – (CB). IMU Operate <open.

PR0 Until Standby light on.

TURN-ON

Standbylight on.

PR0 Until Standbylight off.

Flashing

V37

Q0E Select P00

1f IMU power up desired – (CB)

. IMU Operate – close.

NoAtt light on for 90 seconds.

P06 - AGC Power Down

Source PDF pages: 42

--- PDF page 42 ---

CM-41

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}

P03 (continued)

MARK REJECT

(If mark was unsatisfactory), and

recycle to Flashing V51.

PR0 (if mark was satisfactory), and continue.

~

CMC drives optics LOS to Target 2

Flashing

v51

Optics to Manual – Mark on Target

2.

Flashing

VS50N25

Checklist Code

00016

Terminate mark sequence.

MARK REJECT

(If mark was unsatisfactory), and recycle to prev

ious Flashing V51.

PR0 (If mark was satisfactory), and continue.

Flashing

Alignment Error

V06N93

X XX.XXX d

In Delta Gyro Angles

Y XX.XXX deg

Displays Ysq and Xgy leveling error and Xsyy az

Z XX.XXX deg

V24E to zero Y and leveling errors.

imuth error.

PR0 TorquesZ gyro to eliminate azim

uth error.

V34E Terminates optical verification

and ret

urns to P02

P06–CMC POWER DOWN PROGRA

M

Purpose:

1. To transfer the CMC from the operat

e to the standby condition.

Assumptions:

1. If the computer power is switched off, the AGC Update program (P2) would be done to update the state vector and computer clock time.
2. The AGC is capable of maintaining an accurate value of ground for only 23 hours when in the standby mode. If the AGC is not brought out of standby condition to the running condition at least once within 23 hours, the AGC value of GET must be updated. Once within 23 hours, the AGC value of GET must be updated.
3. Once the program has been selected, the AGC must be put in standby. When POG appears, the AGC will not hold a value (V34E), or an ENTER in response to the request (V37EXXE), a terminal standby,

Sequence of Events:

V37E06E

Flashing

Checklist Code

VS50N25

00062

Power down AGC.

If IMU poweroff desired - (CB). IMU Operate

e <open.

PRO Until Standby light on.

TURN-ON

Standby light on.

PRO Until Standby light off.

Flashing

V37

Q0E Select P00

If IMU power up desired - (CB)

. IMU Operate - close.

NoAtt light on for 90 seconds.

P07 - System Test

No detailed procedure appears in the CMC section; the program is listed in the catalogue only.

P11 - Earth Orbit Insertion Monitor

Source PDF pages: 43

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CM-42

P11-EARTH ORBIT INSERTION MONITOR PROGRAM

Purpose:

the liftoff discrete.

1. To indicate to the astronaut that the AGC has received an attitude error indication on the FDA I error needles, scaled for the attitude error is
2. To generate a choice of 50/15 setting; from liftoff to the beginning of pit

itude and the attitude equal to the difference between the current vehicle attitude and the attitude at liftoff. During the current vehicle attitude and the AGC nominal computation of vehicle attitude based on the stored polynomials in pitch and roll.

3. To display AGC computed trajectory parameters.

4. AGC takeover of Saturn during Boost

- a. Automatic Control—First Stage Only: should the saturn platform set the LV Guidance Switch to the CMC position. This astronaut may as a bias. The Attitude Error current attitude errors will compute the attitude error, subtract the bias, and thereafter will on to the Saturn Instrumentation difference information.

- b. Manual Control—The astronaut may select the Saturn stick function via V46E Attitude Error routine. (DAP configuration = 3). This will terminate the

Assumptions:

- The program is normally automatically selected by the Gyrocompassing program the backup case SIVB. In (P02) when the AGC receives the liftoff discrete from the ER. it would have been selected by keying in V75 ENT ing in V82E.
- The orbit parameter display routine is available by key

Sequence of Events:

V75_ Enter is not keyed unless the liftoff discrete fails and P11 does not start automatically.
P11 displayed – Average G on.
Inertial Velocity Magnitude XXXXX. ft/s
V06N62 Altitude Rate XXXXX. ft/s
Altitude XXXX.X nmi
Pitch/roll polynomial start at liftoff +11.85 second
Terminate polynomial at liftoff +161.35 seconds.
V82E Orbital parameter display.
Apogee Altitude XXXX.X nmi
Flashing Perigee Altitude XXXX.X ami
V16N44 TFF XXbXX min/

Average G off. P00 is selected.

While in P11 will terminate polynomial computations and enable the RHC to steer:

V46E

Saturn vehicle through the AGC interface.

P15 - TLI Initiate/Cutoff

Source PDF pages: 44

--- PDF page 44 ---

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P15-TLI INITIATE/CUTOFF

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Purpose:

1. Provide backup for initiation of Saturn Time Base 6 (TB6), S-IVB, sequence start.
2. Provide TLI burn monitor capability during a Saturn IU controlled (Saturn DAP in IU/Display Operational Mode).
3. Provide automatic TLI shutdown capability during a CMC controlled (Saturn DAP in CMC/Steer Operational Mode).

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Assumptions:

1. The TLI target parameters V1 C/O (velocity magnitude at cutoff), T initiation), and DTF (a bias to compensate for tailoff Delta V and are all available.

46E

Sequence of Events:

V37E15E

Flashing

V06N33

GET of TB6Initiation

'am
vase

:

-

V25E to Load desired TB6 time.

PRO

Flashing

V06N14

Velocity Magnitude at S-IVB Cutoff

V21E to Load desired velocity magnitude

PRO

V06N95

Time From TLI Ignition (TFI)

Velocity to be Gained (Vg)

Velocity Magnitude (VMAGI)

UPLINK activity Light and S-IVB injection sequence start discrete at TB6 start time (TIG minus 9 minutes 38 seconds).

DSKY blanks for 5 seconds at TIG minus 105 seconds.

Average G on at TIG minus 100 seconds.

V06N95 returns.

At ignition plus 10 seconds, R1 equals time from cutoff (TFC).

S-IVB cutoff discrete issued when V1 C/O attained.

Flashing

V16N95

Same as N95 above but

TFC display frozen.

PRO

rthe

|

Flashing

4

v37

Select New Program

P20 - Universal Tracking

Source PDF pages: 45-48

--- PDF page 45 ---

P20 – UNIVERSAL TRACKING

Purpose:

- M attitude/ optics or attitude rates depending on which of the following five options is selected.
- 1, Control CS
 - Option 0 – Point a specified S/C vector along the LOS to the LM without constraining rotation about the vector {VECPPOINT). This option is used to acquire the LM in the SXT field of view and to point the CSM transponder at the LM.
 - Option 1 – Point a specified S/C vector at a specified celestial body without constraining rotation about the vector (VECPPOINT).
 - Option 2 – Perform rotation about a specified S/C vector at a specified rate and beginning at a specified time. This option is normally used to effect PTC or initiate pitchover for landmark tracking.
 - Option 4 – Point a specified S/C vector along the LOS to the LM while constraining rotation about the vector (three-axis). This option is used to acquire the LM in the SXT field of view and to point the CSM transponder at the LM.
 - Option 5 – Point a specified S/C vector at a specified celestial body while constraining rotation about the vector (three-axis).
 2. Update the LM or CSM State vector on the basis of optical tracking VHF range data (Options 0 and 4 only).

Assumptions:

1. The GNCS is normally in control of the vehicle in the Auto mode. If the astronaut assumes control of the vehicle with the RHC, the CSM will remain at the tracking attitude it desired is driven to, Regardless of modeselection the CMC will calculate the desired attitude to orient the optical beacon (Options 0 or 4). The LM is maintaining a preferred tracking attitude to correctly beacon (Options 0 or 4). During rendezvous, the W-matrix is initialized by keying V93E, a freshup start (V36E), and on entering uplinked state vector update, automatically during MINKEY, P22, P23, or P24. The number of marks, The optics and VHF ranging mark counters are used to count the number of marks, counters are zeroed by by source, which are used to update either state vector. The counters are zeroed by t. W-matrix initialization, completion of P37, and by a fresh start. This program may be selected manually or internally by the MINKEY controller.

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P20 (continued)

Sequence of Events:

Option 0 may be initiated automatically by the MINKEY cont

The sequence will start at RENDEZVOUS below if automatic initiation.

V37E20E

Flashing	Option 1D Code	00024
V04No6	Tracking Option Code	0000x

V22E to Load desired option: 0 = Rendezvous (VECPPOINT)
 Celestial body (VECPPOINT)
 Rotation (PTC/ORB rate)
 Rendezvous (Three-axis)
 5 = Celestial body (Three-axis)
 {Option 0 assumed for MINKEY rendezvous}

PRO

Flashing	GAMMA	XXX.XX deg
V06N78	RHO	XXX.XX deg
	OMICRON	XXX.XX deg

V25E to Load the desired coordinates.

GAMMA, RHO are rotational coordinates of the desired pointing axis or axis of rotation. The coordinates represent Euler rotations of the S/C +X axis about the +Z axis and then about the new +Y axis.

SIMBAY pointing = 90°, 52.25°

COAS pointing 0°, 0°

Optics pointing 0°, -35°

PTC rotation 0°, 0°

Orb rate rotation = 90°, 0°

{Optics coordinates are assumed for rendezvous but may be changed at anytime.)

OMICRON is an attitude constraint about the pointing vector for three-axis options. It is ignored in VECPOINT options.

0° = Heatshield forward

180° = Apex forward

PRO

Flashing	_Desired Rate (Option 2 only)	X.XXXX deg/s
V06N79	Desired Deadband	XXX.XX deg

V24E to Load desired rate and deadband.

PRO to appropriate option

CELESTIAL BODY TRACK

Flashing	Star 1D Code -	000xxX
V01N70		

V21E to load desired Star Code.

PRO If Star Code # 00, Go to RENDEZ VOUS

Flashing	Unit position vector	X .XXXXX
V06N88	of desired planet	Y .XXXXX
		Z .XXXXX

V25E to load position vector.

PRO to RENDEZVOUS

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P20 (continued)

ROTATION

Flashing	GET at which rotation	00XXX h
V06N34	maneuver is to start	000XX min
		0XX.XXs

V25E to load desired GET (all 0's specify present time)

PRO to TERMINATE (rotation will commence at specified GET)

RENDEZVOUS

Flashing	Desired FDAI angles	OG(R)	XXX.XX deg
V50N18	for automaneuver	IG(P)	XXX.XX deg
		MG(Y)	XXX.XX deg

PRO

VOEN18	Maneuver in Progress
Flashing	Maneuver Complete
V50N18	

ENTER Terminates automaneuver routine. If rendezvous option, go to appropriate marking sequence, otherwise go to TERMINATE.

Note: R61 maintains tracking attitude computation. If the attitude error between the vehicle pointing axis and the LOS to the target is greater than 10 degrees, the astronaut will be alerted by:

UPLINK ACTY light on

V58E

Request automaneuver routine. Go to RENDEZVOUS and execute automaneuver.

OPTICS MARKING

The rendezvous sighting mark routine is called automatically. Proceed with optics marking.

VHF RANGE MARKING

If MINKEY controller active, VHF marking is initiated automatically when the range is within 327.67 nmi.

V87E Sets VHF Range Flag manually.

Enables ranging marks for use by R22 at 1-minute intervals.

V88E Resets VHF Range Flag manually.

Disables ranging marks. Use V87E to reenables.

BACKUP COAS MARKING

VS4E Calls the backup sighting mark routine.

Flashing	Optics angle coordinates	Shaft	XXX.XX deg
V06N94	for alternate LOS (COAS)	Trunnion	XX.XXX deg

V24E to load coordinates.

COAS LOS coordinates can be determined by sighting on a boresight star and using P52 to compute the desired optics angles to acquire the star in the SXT field.

PRO

Flashing	MARK Counter (VHF - Optics)	XXbXX
V53N45,	TFI of Next Burn	XXbXX min/s
MGA at TIG		XXX.XX deg

ENTER Used for marking with COAS. V86E is used to reject a backup mark

Note: N79 may be modified to specify +X axis pointing for COAS marking at any time. The program will calculate a maneuver to +X axis tracking attitude.

P20 (continued)

UPDATE DISPLAY

If any mark produces a state vector position or velocity magnitude change greater than a preloaded value, the astronaut receives a display of the data for approval/disapproval.

Flashing	Delta R	XXXX.X nmi
V06N49	Delta V	XXXX.X ft/s
	Source Code (1-OPT, 2~VHF)	0000x

PRO Uses data and updates the state vector.

V32E Rejects mark data and state vector update not done.

TERMINATE

VS6E

Flashing	
v3?	Select New Program

P21—GROUND TRACK DETERMINATION PROGRAM

Purpose

1. Provide astronaut with details of his ground track.

Assumptions:

1. Can be used while CSM is in either earth or lunar orbit to determine ground track of either LM or CSM.
2. Vehicle whose ground track parameters are calculated to remain in freefall from the present time until T Lat Long.

Sequence of Events:

V37E21E

Flashing	Option Code(specify vehicle)	00002
----------	------------------------------	-------

V04N06

Vehicle Code (1-CSM, 2-LM)	00001
----------------------------	-------

CSM is assumed; if LM is desired, V22E2E

PRO

Flashing	Time Lat/Long	00x Xx. h
V06N34		000XX. min
		YN.XX 5

V25E. Key in time at which vehicle position is desired.
Time= 0 specifies present time.

PRO

Flashing	Latitude of Vehicle	XXX.XX deg (+ north)
V06N43	Longitude of Vehicle	XXX.XX deg (+ east)
	Altitude Above Launch Pad/ Landing Site	XXXX.X nmi

V32E recycles to Flashing V06N34 for new display.

V06N73E Optional Display

Flashing	Altitude	XXXXXb Ami
V06N73	Velocity	XXXXX. ft/s
	Flight Path Angle	XXX.XX deg

KEY REL

Flashing	Same as N43 above.
V06N43	

PRO

Flashing	Select New Program.
V37	

P21 - Ground Track Determination

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P20 (continued)

UPDATE DISPLAY

If any mark produces a state vector position or velocity magnitude change greater than a preloaded value, the astronaut receives a display of the data for approval/disapproval.

Flashing	Delta R	XXXX.X nmi
V06N49	Delta V	XXXX.X ft/s
	Source Code (1-OPT, 2-VHF)	0000x

PRO Uses data and updates the state vector.

V32E Rejects mark data and state vector update not done.

TERMINATE

VS6E

Flashing	
v3?	Select New Program

P21—GROUND TRACK DETERMINATION PROGRAM

Purpose

1. Provide astronaut with details of his ground track.

Assumptions:

1. Can be used while CSM is in either earth or lunar orbit to determine ground track of either LM or CSM.
2. Vehicle whose ground track parameters are calculated to remain in freefall from the present time until T Lat Long.

Sequence of Events:

V37E21E

Flashing	Option Code (specify vehicle)	00002
V04N06		

	Vehicle Code (1-CSM, 2-LM)	00001
--	----------------------------	-------

CSM is assumed; if LM is desired, V22E2E

PRO

Flashing	Time Lat/Long	00x Xx. h
V06N34		000XX. min
		YN.XX 5

V25E. Key in time at which vehicle position is desired.

Time= 0 specifies present time.

PRO

Flashing	Latitude of Vehicle	XXX.XX deg (+ north)
V06N43	Longitude of Vehicle	XXX.XX deg (+ east)
	Altitude Above Launch Pad/ Landing Site	XXXX.X nmi

V32E recycles to Flashing V06N34 for new display.

V06N73E Optional Display

Flashing	Altitude	XXXXXb Ami
V06N73	Velocity	XXXXX. ft/s
	Flight Path Angle	XXX.XX deg

KEY REL

Flashing	Same as N43 above.
V06N43	

PRO

Flashing	Select New Program.
V37	

P22 - Orbital Navigation

Source PDF pages: 49-50

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P22-ORBITAL NAVIGATION PROGRAM

Purpose:

1. Locate and track landmark suitable for navigation purposes.
Obtain sighting marks on chosen landmark.

SOEeMNAAEYWN

Calculate the orbital parameter changes generated by landmark sightings.
Update state vector as result of sightings (if sightings ok).
Update coordinates of known landmarks.
Provide coordinates of unknown landmarks.
Track preloaded landing site.
Provide coordinates of new landing site.
Provide coordinates of an offset landing site.
Align optics along an advanced orbit ground track for purpose of tracking and mapping a new landing site.

Assumptions:

1. There are two types of landmark tracking methods:
 - a. "Known" Landmark Tracking—The tracking of an earth landmark made known to the AGC by latitude, longitude/2, and altitude, and the tracking of a lunar landmark made known to the AGC by its latitude, longitude/2, and altitude.
 - b. "Unknown" Landmark Tracking—The tracking of a landmark or surface feature identified to the AGC as an unknown landmark, one whose coordinates are not known.
2. There are two types of landing site mapping methods:
 - a. Landing Site Designation—Track and mark on an unknown landmark. Store the resulting coordinates in Landmark Code 01. If mapping only is desired (that is, no state vector calculation or corrections), the astronaut need take only one mark.
 - b. Landing Site Offset—While tracking and marking on a primary landmark (known or unknown), point the optics SLOS at the chosen landing site and mark it once, (at least one mark on the primary landmark must have been made prior to this), then continue marking on the primary landmark. Store the resulting coordinates of the offset landing site in Landmark Code 01.
3. Acquisition of a landmark may be aided by the AGC by use of the Automatic Optics Positioning routine (R52).
4. Acquisition of a preloaded landing site may be aided by keying Landmark Code 01 into the V05 N70 display for use by the Automatic Optics Positioning routine (R52).
5. The Ground Track Determination program (P21) is available to aid the crew in choosing appropriate landmarks prior to selection of this program.
6. The Ground Track Determination program (P21) is available to the crew following this program to provide updated ground track information.
7. Possible attitude control methods might be as follows (in all cases care must be taken to monitor possible impending IMU gimbal lock).
 - a. Manual control by the pilot or navigator with the rotational hand controller.
 - b. Manual rate control by the navigator with the minimum impulse control in the GNC free mode.
 - c. Automatic pitchover maneuver via P20, Option 2.
8. Selection of this program will terminate Options 0 and 4 of P20.

Sequence of Events:

V37E22E

Flashing Maximum MGA with Spacecraft X Axis
 V06N45 in Orbital Plane (R3) XXX.XX deg
 If expected MGA is greater than 60 degrees, exit P22 and realign IMU (P52).

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CM-49

P22 (continued)

ZERO Optics for 15 seconds.

OPTICS Mode ~ CMC

PRO If in earth orbit go to Flashing V06N89 below.

Flashing Landmark Code (R2) ABCDE
 V0SN70

A=1 (known landmark), 2 (unknown landmark)

B > index of offset indicator

C = not used

DE = Landmark ID (00, 01, or 5X)

PRO If A = 2, go to Flashing V51; if A = 1 and DE ≠ 00, go to Flashing V06N92

Flashing Landmark Latitude XX.XXX deg

V06N89 - Longitude/2 XX.XXX deg

Altitude of LMK XXX.XX ami

V25E. Load landmark coordinates

PRO

V06N92 -Auto position optics to landmark or, if DE = 5X.
 10 60 degrees ahead of vehicle location on ground
 track

Maneuver vehicle at orbital rate for tracking.

OPTICS Mode - Manual

Flashing

v51

Request remarks.

MARK

Offset landing site mark followed by V52E

Flashing Checklist Code 00016 (After
 VSON25 five marks taken)

PRO Terminate mark sequence.

Flashing Same as N70 above. ABCDE

V0SN71

V25E to correct data.

(insure 8 corresponds to the mark on offset landing site or is set to zero.)

PRO

Flashing Same as N89 above.

V06N89

V25E to correct data.

PRO

Flashing Delta R XXXX.X ami

V06N49 Deita V XXXX.X ft/s

Change in position and velocity magnitudes with incorporation of landmark sighting.

PRO Accepts data. V32E to reject data and recycle to Flashing V0SN70.

Flashing

V06N89

Same as N89 above except an update of landmark
 coordinates or map of offset landing site coordinates
 or map of unknown landmark. If this landmark or offset
 landing site is desired as the new landing site, key PRO to
 update landing site coordinates and recycle to Flashing

V34E V05N70 display. To retain landing site but redo the tracking, key V32E and recycle to Flashing V05N70 display.

Flashing v37 Select New Program.

P23 - Cislunar Midcourse Navigation

Source PDF pages: 51-53

--- PDF page 51 ---

CM-50

P23-CISLUNAR MIDCOURSE NAVIGATION PROGRAM

Purpose:

- To do midcourse navigation by incorporation of star/earth and star/moon optical measurements.

Assumptions:

- Prior to each mark the program will call for an optics calibration which may be done or bypassed dependent upon the stability history of the calibration. To perform the mark the astronaut should finally select minimum impulse control (either GNCS or SCS) and the optics should be in manual in order to maintain the fix. The optics should be on for 15 minutes prior to marking. The AGC does not check for moon/earth occultation or sun brightness in this program. Nouns 70 and 71 are checked to assure that the codes fall within certain permissible limits. (Check to assure that R2 and R3 do not both equal zero or do not both not equal zero, R1 = 0 to 37 (octal), R2 = ABCDE, C = 1 or 2, R3 = ABCDE, C and D = 1 or 2). Noun 89 is also checked to assure that the values for R1 and R2 fall within certain defined limits (-90 degrees to +90 degrees).
- Noun 88 allows that any proportional set of components may be loaded for planet direction. However, a unit vector is recommended.
- Selection of this program will terminate Options 0 and 4 of P20.

Sequence of Events:

V37E23E

	Flashing	Checklist Code		00015
	V50N25			
	Perform celestial body acquisition.			
PRO	If manual acquisition desired, key ENTER and go to Flashing V59.			
	Flashing	Star ID Code		000 xx
	V01N70			
	V21E to load star code XX.			
PRO	If star ID # 00, go to Flashing V50N18.			
	Flashing	Unit Position	X	.XXXXX
	V06N88	Vector of Planet	Y	.XXXXX
			Z	.XXXXX
	V25E to load planet vector.			
PRO				
	Flashing	Desired FDAI Angles for	OG(R)	XXX.XX deg
	V50N18	Automanuever	IG(P)–	XXX.XX deg
			MG(Y)	XXX.XX deg
OPTICS ZERO for 15 seconds				
OPTICS Mode ~ Manual				
PRO	Automanuever LLOS to selected star.			
	V06N18	Maneuver in process.		

Flashing Maneuver complete.
 VSON18
 ENTER Terminate maneuver routine.
 Flashing Request optics calibration mark.
 V59
 To bypass optics calibration, key ENTER and go to Flashing V0SN70.

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P23 (continued)

MARK LLOS and SLOS superimposed on star.
 Flashing Trunnion Bias (R2) XX.XXX deg
 V06N87
 Mark may be repeated for additional bias computations.
 PRO V32E will recycle to Flashing VSON25
 Flashing Star 1D Code 000 xx
 V05N70 Landmark 1D ABCDE
 Horizon 10 00F G0
 V25E to load desired data.
 ABDE = not used
 C = (earth landmark), 2 (lunar landmark)
 learth horizon), 2 (lunar horizon)
 G = 1 (near horizon), 2 (far horizon)
 (if R2 # 0, R3 = 0) or (if R2 = 0, R34 0)
 PRO \f PLANET/HOR sighting, go to Flashing V06N88.
 If STAR/HOR sighting, go to Flashing VSON25.
 Flashing _Latitude of Landmark XX.XXX deg
 V06N89 -_Longitude/2 XX. XXX deg
 Altitude XXX.XX ami
 V25E to load landmark coordinates.
 PRO If STAR/LMK sighting, go to Flashing VSON25.
 Flashing Unit Planet Vector X .XXXXX
 V06N88 Y .XXXXX
 Z .XXXXX
 V25E to load planet vector.
 PRO Flashing Checklist Code 00202
 VSON25
 Request automaneuver LLOS to LMK/HOR.
 PRO Specifies a 3-axis maneuver. ENTER may be used to specify VECPOINT computed
 maneuver which, if necessary, provides gimbal lock avoidance.
 Flashing Same as N18 above. Request automaneuver.
 V50N18
 PRO V06N18 Same as N18 above. Maneuver in process.
 Flashing Same as N18 above. Maneuver complete
 V50N18
 A V94E may be used to reacquire the landmark with an automaneuver.
 OPTICS Mode - CMC
 ENTER Terminate automaneuver and autoposition.
 Optics SLOS to the selected STAR/PLANET.
 V06N92 Desired Optics Angles
 Shaft XXX.XX deg

i
 ia
 f
 t
 |
 i

Trunnion XX.XXX deg

OPTICS Mode – Manual

Flashing
V51Request Mark (STAR/PLANET and LMK/HOR
superimposed).Flashing
VSON25

Checklist Code

--- PDF page 53 ---

P23 (continued)

PRO Terminate mark sequence.

Flashing Same as N70 above.
V05N71

V25E to correct data.

PRO If PLANET/HOR sighting, go to Flashing V06N88.

If STAR/HOR sighting, go to Flashing V06N49.

Flashing

V06N89 Same as N89 above

V25E to correct landmark coordinates

PRO If Star/LMK sighting, go to Flashing V06N49

Flashing Same as N88 above.
V06N88

V25E to correct planet vector.

PRO State vector update computed.

Flashing Delta R XXXX.X ami
V06N49 Delta V XXXX.X ft/sMagnitude of the position and velocity vector changes displayed for astronaut
approval.

PRO Acceptdata. V32E reject data, go to Flashing V37.

Flashing Select New Program.
Vv37

P24—RATE AIDED OPTICS TRACKING PROGRAM

Purpose:

1. To locate and acquire a given landmark via the automatic optics positioning routine (R52) with the Optics Mode switch in the CMC position. i
2. When acquired, to track the given landmark via the rate-aided optics feature of the automatic optics positioning routine with the optics in the Manual position. i
3. To obtain and downlink to the ground an unlimited number of sighting marks on the chosen landmark and to update the landmark coordinates. ;

Assumptions:

1. The coordinates of the landmark are known approximately.
2. At low altitudes, tracking may be facilitated by manually initiating a pitch-over maneuver via P20, Option 2.
3. The astronaut will assist in the tracking of the chosen landmark when in the rate-aided mode (Optics switch in Manual) by supplying inputs via the optics hand controller.
4. Selection of this program will terminate Options 0 and 4 of P20.

P24 - Rate Aided Optics Tracking**Source PDF pages:** 53-54

--- PDF page 53 ---

P23 (continued)

```

PRO    Terminate mark sequence.
        Flashing      Same as N70 above.
        V05N71
V25Eto correct data.
PRO    If PLANET/HOR sighting, go to Flashing V06N88.
        If STAR/HOR sighting, go to Flashing V06N49.
        Flashing
        V06N89      Same as N89 above
V25E to correct landmark coordinates
PRO    If Star/LMK sighting, go to Flashing V06N49
        Flashing      Same as N88 above.
        V06N88
V25E to correct planet vector.
PRO    State vector update computed.
        Flashing      Delta R      XXXX.X ami
        V06N49      Delta V      XXXX.X ft/s
        Magnitude of the position and velocity vector changes displayed for astronaut
        approval.
PRO    Acceptdata.      V32E reject data, go to Flashing V37.
        Flashing      Select New Program.
        Vv37

```

P24—RATE AIDED OPTICS TRACKING PROGRAM

Purpose:

1. To locate and acquire a given landmark via the automatic optics positioning routine (R52) with the Optics Mode switch in the CMC position. i
2. When acquired, to track the given landmark via the rate-aided optics feature of the automatic optics positioning routine with the optics in the Manual position. i
3. To obtain and downlink to the ground an unlimited numberof sighting marks on the chosen landmark and to update the landmark coordinates. ;

Assumptions:

1. The coordinates of the landmark are known approximately.
2. At low altitudes, tracking may be facilitated by manually initiating a pitch-over maneuvervia P20, Option 2.
3. The astronaut will assist in the tracking of the chosen landmark when in the rate-aided mode (Optics switch in Manual) by supplying inputs via the optics hand controller.
4. Selection of this program will terminate Options 0 and 4 of P20.

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P24 (continued)

Sequence of Events:

```

V37E24E
        Flashing      Landmark Latitude      XX.XXX deg
        V06N89      Longitude/2      XX.XXX deg
                        Altitude      XXX.XX nmi
        V25E to load approximate landmark coordinates.
ZERO OPTICSfor 15 seconds.
OPTICS Mode – CMC

```

```

PRO                                V06N92      Desired Optics Angles
;
                                Shaft      XXX.XX deg
                                Trunnion XX.XXX deg
AGC will auto-position the optics LOS to the landmark. The AGC will update the
desired optics angles each 0.05 second plus integration time.

OPTICS Mode – Manual
    Flashing      AGC will now compute optics drive rates to maintain
    V51           the landmark track by back differencing the desired optics
                  angles and compensating for computational and system delays.
                  Desired optics angles are updated with state vector and landmark
                  updates.
Adjust tracking rate with optics hand controller
Provide a manual optics drive assist to trim the AGC commanded drive rate for
aligning the target and reticle. AGC commanded rates are updated through subsequent
marking and landmark updates.
MARK
Unlimited marking is accepted. Marks are transmitted downlink and are used to update
the landmark coordinates when the number of R52 cycles since the last landmark up-
date reaches a prelaunch erasable value. The landmark update is subsequently used to
update the desired optics drive rate and maintain the landmark track.
PRO Terminates Program.
    Flashing      Select New Program
    V37

```

P27 - AGC Update

Source PDF pages: 55

--- PDF page 55 ---

CM-54

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|

P27—AGC UPDATE PROGRAM

Purpose:

1. To insert information into the AGC via the digital uplink by transmission from the ground or via the DSKY keyboard by crew manual input.

Assumptions:

1. AGC updates are of four categories:
 - a. Provide an update for AGC liftoff time (V70).
 - b. Provide an octal increment for the AGC clock only (V73). i
 - c. Provide load capability for a block of sequential erasable locations (1-18 inclusive locations whose address is specified) (V71). j {
 - d. No load capability for 1-9 inclusive individually specified erasable locations
2. Update is allowed in the CSM when the AGC is in P00, P02 or P20 (Options 1, 2 or 5), and if the DSKY is available.
3. The UPTTEL Accept/Block switch must be in Accept for telemetry update. update via the ground by
4. The automatic mode of update is program selection and manual selection by the
uplink transmission. The only difference between this and the astronaut rather than

astronaut is that the DSKY responses are keyed in by transmitted,

Sequence of Events:

V37E00E

Select P00 if not selected.

Up Telemetry switch – Accept

Enable Uplink.

Uplink Acty light – On

Program selected via Uplink. Mode window displays 27.

V37E00E

Select P00.

Up Telemetry switch – Block

Disable uplink.

P29 - Time-of-Longitude

Source PDF pages: 56

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P29-TIME OF LONGITUDE

Purpose:

1. To provide the astronaut with an estimated time of Passage over a selected longitude.

Assumptions:

1. This program may be selected while the CSM is in either earth or lunar orbit to find the time of longitude of either the CSM or LM.
2. This Program assumes the vehicle whose ground track parameters are calculated remains in freefall from the selected start time until the time of longitude crossing.

Sequence of Events:

V37E29E

Flashing	Option 1D Code	00002
V04N06	Vehicle Option (1-CSM, 2-LM)	0000

V22E to load desired vehicle code.

PR0

Flashing	GET at which CMC	00X XX h
V06N34	begins search(all 0's for present time)	000XX min
		0XX.XXs

V25E to load desired time.

PR0

Flashing	Desired Longitude (R2)	XXX.XX deg
V06N43		

V22E to load desired longitude.

PR0

Flashing	Time of longitude crossing	00XXX h
V06N34	by specified vehicle	000XX min
		0XX.XX 5

V32E to previous flashing V06N43 to change longitude.

PR0

Flashing	Latitude at Longitude Crossing	XXX.XX deg
V06N43	Longitude Specified	XXX.XX deg
	Altitude of Vehicle at Longitude Crossing	XXXX.X nmi

V32E to Flashing V04N006 to recycle.

PR0

Flashing	
V37	Select New Program

P30 - External Delta V

Source PDF pages: 57

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CM-56

P30-EXTERNAL DELTA V PROGRAM

Purpose:

1.
- To accept targeting parameters obtained from a source(s) external to the AGC and compute therefrom the required velocity and other initial conditions required by the AGC for execution of the desired maneuver. The targeting parameters inserted into the AGC are the time of ignition (TIG) and the impulsive Av along CSM local vertical axes at TIG.

Assumptions:

1.
- Target parameters (TIG and AV(LV)) may have been loaded from the ground during a prior execution of P27.
2.
- External Delta V flag is set during the program to designate to the thrusting program that external Delta V steering is to be used.

Sequence of Events:

V37E30E	Flashing V06N33	Ground Elapsed Time of Ignition (TIG)	00XXX.h 000 XX. min 0XX.XX s
	V25E to load desired TIG.		
PRO	Flashing V06N81	Impulsive Delta V at TIG in Local Vertical Coordinates	xx XXXX.X Y XXXX.X Z XXXX.X
	V25E to load desired Delta V.		
PRO	Flashing V06N42	Apogee/Apolune Altitude Perigee/Perilune Altitude Magnitude of Delta V at TIG	XXXX.X nmi XXXX.X ami XXXX.X ft/s
PRO	Flashing V16N45	Mark Counter (VHF-Optics) Time from Ignition (TF1) Middle Gimbal Angle at T!IG with Vehicle +X Axis in Direction of Thrust	XXbXX marks XXbXX min/s XXX.XX deg
	If the REFSMMAT flag is reset (that is, the IMU is not aligned) MGA will equal -00002.		
PRO	Flashing V37	Select New Program.	

P31 - CSM Height Adjustment Maneuver (HAM)

Source PDF pages: 58-60

--- PDF page 58 ---

CM-57

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P31-HEIGHT ADJUSTMENT MANEUVER (HAM) PROGRAM

Purpose:

1.
- To calculate the parameters associated with the Height Adjust Maneuver (HAM) for

Delta V burns.

g 2. To store the HAM target parameters for use by the desired thrusting program.

n : Assumptions:

1. At a selected TPI time the line of sight between the CSM and the LM is selected to be a prescribed angle (E) from the horizontal plane defined at the active position.
2. CDH Delta V is selected to minimize the variation of the altitude difference between the orbits.
3. HAM burn is defined such that the impulsive Delta V is in the horizontal plane defined by the active vehicle position at HAM ignition.
4. The pericenter altitude of the orbit following CSI and CDH must be greater than 35,000 ft (lunar orbit) or 85 nmi (earth orbit) for successful completion of the program.
5. The CSI and CDH maneuvers are originally assumed to be parallel to the plane of the LM orbit. Out-of-plane parameters are computed for TIG (HAM) and displayed. In addition, the N81 display is modified to establish an antinode at HAM. If P20 is in operation while the program is operating, the astronaut may hold at 2 flashing display and turn on the rendezvous sighting mark routine, take optics marks and/or allow VHF ranging marks to accumulate.
7. TIG (HAM) is computed to be 180 degrees central angle before TIG (CSI).
8. The ISS need not be on to complete this program unless automatic state vector updating is desired by the Universal Tracking program (P20).
9. The external Delta V flag is set during this program to designate to the thrusting program that external Delta V steering is to be used.
- i 10. This program may be selected manually or internally by the MINKEY controller.

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P31 (continued)

Sequence of Events:

\f entered automatically by MINKEY controller, go to MANEUVER.

V37E31E

Note: If P20 rendezvous option is not running, P20 Option is activated now.

Flashing	MINKEY Rendezvous Option	
VS50N25	Checklist Code	00017

PRO_ Elects MINKEY automatic rendezvous sequencing.

ENTER Elects manual sequencing.

MANEUVER

If the tracking attitude error between the vehicle pointing axis and the LOS to the LM is less than 10 degrees (computed by P20/R61), go to TARGETING.

Flashing	Desired FDAI angles for	OG(R)	XXX.XX deg
V50N18	Automanuever	iG(P)	XXX.XX deg
		MG(Y)	XXX.XX deg

PRO

V06N18 Maneuver in Progress

If MINKEY sequence, go to TARGETING when maneuver is completed.

Flashing	
V50N18	Maneuver Complete (manual sequence)

ENTER Terminates automaneuver routine; go to TARGETING.

Note: P20 (R61) will maintain tracking attitude computations. If the attitude error

becomes greater than 10 degrees, the astronaut will be alerted by:
UPLINK ACTYlight on.

V58E

Request automaneuver execution; go to MANEUVER.

TARGETING

Flashing	GET of CSI Ignition TIG (CSI)	00XXX h
V06N11		000XX min
		0XX.XX s

V25E to load desired TIG.

PRO

Flashing	Apsidal Crossing	0000x
V06N55,	Elevation Angle	XXX.XX deg
	CENTANG	XXX.XX deg

V25E to load desired data.

Apsidal crossing is the future line of apsis crossing where TIG (CDH) is to occur.
Elevation angle is the angle between the CSM/LM LOS and the CSM local horizon

al

plane at TIG (TPI).

(For LM solution (P72), angle is between LM/CSM LOS and the LM local horizontal.)

CENTANG is an option code where R3 # 0 specifies TIG (CDH) to occur at N (180)
degrees from CS maneuver and N = number entered in R1.

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P31 (continued)

PRO

Flashing	GET of TPI Ignition TIG (TPI)	00XXXh
V06N37		000XX min
		0XX.XXs

V25E to modify TIG.

PRO

Flashing	GET of HAM Ignition TIG (HAM)	00XXX h
V06N33		000XX min
		0XX.XX \$s

V25E to modify TIG.

PRO

Flashing	Mark Counter (VHF-Optics)	XXbXX
V16N45	Time from Ignition TF] (HAM)	XXbXX min/s
	MGA	-00001

Mark counter updated by P20 which is running in the background.

MGA is displayed on the final pass through the program.

PRO Sets Final flag to execute final pass through program.

V32E Continues but Final flag not set.

Alarm Codes 00600 through 00606 may occur. If an alarm occurs, V32E recycles
to V06N11 where the INPUT parameters may be adjusted for a new solution.

Flashing	Out-of-Plane Position (Y), Active Vehicle	XXX.XX nmi	{
V06N90	Out-of-Plane Velocity (YDOT), Active Vehicle	XXXX.X ft/s	i
	Out-of-Plane Velocity (Y DOT), Passive Vehicle	XXXX.X ft/s	

PRO

Flashing	Delta V at TIG (HAM)	x	XXXX.X ft/s
V06N81	In Local Vertical Coordinates	Y	XXXX.X ft/s
		Zz	XXXX.X ft/s

V25E to modify Delta V.

PRO If Final flag not set go to previous flashing V16N45

Flashing	Mark Counter (VHF-Optics)	XXbXX
V16N45	TFI (HAM)	XXbXX min/s
	MGA	XXX.XX deg

MGA will be the MGA at TIG (HAM). If the IMU is not aligned, MGA will be -00002. (For LM solution (P72) MGA is always -00002 on the final pass.)

PRO

If MINKEY controller is active, W matrix reinitialization is performed and the appropriate burn program is initiated.

If Delta V solution < 7 ft/s, P41 is initiated.

If Delta V solution 2 ft/s, P40 is initiated.

Flashing

V37

Select New Program (manual sequence)

P32 - CSM Coelliptic Sequence Initiation (CSI)

Source PDF pages: 61-63

--- PDF page 61 ---

CM-60

P32---CSM COELLIPTIC SEQUENCE INITIATION (CSI) PROGRAM

Purpose:

1. To calculate parameters associated with the following concentric flight plan maneuvers: the Coelliptic Sequence Initiation (CS!) and the Constant Delta Altitude maneuver (CDH), for Delta V burns.
2. To store the CSI target parameters for use by the desired thrusting program.

Assumptions:

1. At a selected TPI time the line of sight between the CSM and the LM is selected to be a prescribed angle (E) from the horizontal plane defined at the active position.
2. The time between CSI ignition and CDH ignition must be computed to be greater than 10 minutes for successful completion of the program.
3. The time between CDH ignition and TP! ignition must be computed to be greater than 10 minutes for successful completion of the program.
4. COH Delta V is selected to minimize the variation of the altitude difference between the orbits.
5. CSI burn is defined such that the impulsive Delta V is in the horizontal plane defined by the active vehicle position at CS! ignition.
6. The pericenter altitude of the orbit following CSI and CDH must be greater than 35,000 feet (lunar orbit) or 85 nmi (earth orbit) for successful completion of this program.
7. The CSI and COH maneuvers are originally assumed to be parallel to the plane of the LM orbit. However, out-of-plane parameters are computed for TIG (CSI) and displayed. In addition, the N81 display is modified to establish an antinode at CSI.
8. If P20 is in operation while the program is operating, the astronaut may hold at any flashing display and take optics marks and/or allow VHF ranging marks to accumulate.
9. The ISS need not be on to complete this program unless automatic state vector updating is desired by the Universal Tracking program (P20).
10. The external Delta V flag is set during this program to designate to the thrusting program that external Delta V steering is to be used.
11. This program may be selected manually or internally by the MINKEY controller:

Sequence of Events:

\f entered automatically by MINKEY controller, go to MANEUVER.

V37E32E

Note: If P20 rendezvous option is not running, P20 Option is activated now.

Flashing MINKEY Rendezvous Option

V50N25 Checklist Code

00017

hi PRO Elects MINKEY automatic rendezvous sequencing.

ENTER Elects manual sequencing.

\ MANEUVER

i] If tracking attitude error between the vehicle pointing axis and the LOS to the LM is less than 10 degrees (computed by P20/R61), go to TARGETING.

Flashing Desired FDAI angles for OG(R) XXX.XX deg

V50N18 Automaneuver 1G(P) XXX.XX deg

MG(Y) XXX.XX deg

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CM-61

P32 (continued)

PRO

V06N18 Maneuver in Progress

!f MINKEY sequence, go to TARGETING when

maneuver is complete.

Flashing

V50N18 Maneuver Complete (manual sequence)

ENTER Terminates automaneuver routine. Go To TARGETING

G.

Note: P20 (R61) will maintain tracking attitude

computations. If the attitude error becomes greater than 10 degrees, the astronaut will

be alerted by

UPLINK ACTY light on

V58E

Request automaneuver execution. Go to MANEUVER

TARGETING

Flashing GET of CSI Ignition TIG (CSI)

V06N11

00XXX h

000XX min

0XX.XX s

V25E to load desired TIG

PRO

Flashing Apsidal Crossing

V06N55

o0000x

Elevation Angle

XXX.XX deg

CENTANG

XXX.XX deg

V25E to load desired data.

Apsidal crossing is the future line of apsis crossing

where TIG (CDH) is to

occur.

Elevation angle is the angle between the CSM/LM

LOS and the CSM local horizontal

plane at TIG (TPI)

(For LM solution (P72) angle is between LM/CSM LOS and the LM local horizontal)

CENTANG is an option code where R3# 0 specifies TIG (CDH) to occur at N(180) degrees from CSI maneuver and N = number entered in R1

```

PRO          Flashing      GET of TPI Ignition TIG (TP1)
              V06N37
                                00XXX h
                                000XX min
                                0XX. XXs

```

V25E to load desired TIG.

PRO	Flashing V16N45	Mark Counter (VHF-Optics)	XXbXX
		Time from Ignition TFI (CSI)	XXbXX min/s
		MGA	-00001

Mark Counter updated by P20 which may be running in the background

MGA is only displayed on the final Pass through the program

enero nnn

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P32 (continued)

PRO Set Final flag.
V32 continues in program but Final flag is not set. Used when another pass is desired.
Alarm Codes 00600 through 00606 may occur. If an alarm occurs, V32E recycles to V0G6N11 where the input Parameters may be adjusted for a new solution.

```
|f automatic MINK      EY sequence, go to flashing V06N90.
      Flashing        Delta Altitude at TIG (CDH)
      V06N75          XXXX.X nmi
                      Delta Time of TIG (CSI/CDH)
                      XXbXX min/s
                      Delta Time of TIG (CDH/TP1)
                      XXbXX min/s
TIG (CDH) is available by keying V06N13
                      E.
```

PRO	Flashing V06N90	Out-of-Plane Position (Y) Active Vehicle	XXX. XX ami
		Out-of-Plane Velocity (YDOT) Active Vehicle	XXXX.X ft/s
		Out-of-Plane Velocity (YDOT) Passive Vehicle	XXXX.X ft/s

PR0	Flashing	Delta V at TIG (CSI)	x	XXXX.X ft/s
-----	----------	----------------------	---	-------------

	V06N81	In Local Vertical Coordinates	Y	XXXX.X ft/s
			2	XXXX.X ft/s
PRO	If automatic MINKEY sequence, go to Flashing V16N45.			
	Flashing V06N82	Delta V at TIG (CDH)	x	YXXX.X ft/s
		In Local Vertical Coordinates	Y	XXXX.X ft/s
			Zz	XXXX.X ft/s
PRO	If Final flag is reset, go to previous Flashing V16N45.			
	Flashing V16N45	Mark Counter (VHF -Optics)		XXbXX
		TFI (CSI)		XXbXX min/s
		MGA		XXX.XX deg
	MGA will be the MGA at TIG (CSI). If the IMU is not aligned, MGA will be -00002. (For LM solution (P72) MGA is always -00002 on the final pass.)			
PRO	If MINKEY controller is active, W-matrix reinitialization is performed and the appropriate burn program is initiated.			
	If Delta V solution < 7 ft/s, P41 is initiated.			
	If Delta V solution > 7 ft/s, P40 is initiated.			
	Flashing V37	Select New Program (manual sequence)		

P33 - CSM Constant Delta Altitude (CDH)

Source PDF pages: 64-65

--- PDF page 64 ---

CM-63

PROGRAM

P33-CSM CONSTANT DELTA ALTITUDE (CDH)

Purpose:

- To calculate parameters associated with the Constant Delta Altitude maneuver (CDH), for Delta V burns.
- To store the CDH target parameters for use by the desired thrusting program.

Assumptions:

- This program is based upon previous completion of the Coelliptic Sequence Initiation (CS!) program (P32). Therefore:
 - At a selected T_{Pi} time (now in storage) the line of sight between the CSM and LM was selected to be a prescribed angle (E) (now in storage) from the horizontal plane defined at the active vehicle position.

- b. The time between CSI ignition and CDH ignition was computed to be greater than 10 minutes.
 - c. The time between CDH ignition and TPI ignition was computed to be greater than 10 minutes.
 - d. The variation of the altitude difference between the orbits was minimized.
 - e. CSI burn is defined such that the impulsive Delta V is in the horizontal plane defined by the active vehicle position at CSI ignition.
 - f. The pericenter altitudes of the orbits following CSI and CDH were computed to be greater than 35,000 feet (lunar orbit) or 85 nmi (earth orbit).
 - g. The CSI and CDH maneuvers were assumed to be parallel to the plane of the LM orbit. However, out-of-plane parameters are computed for TIG (CDH) and displayed. In addition, the N81 display is modified to establish an anti-node at CDH.
2. If P20 is in operation while this program is operating, the astronaut may hold at any flashing display and take optics marks, and/or he may allow VHF ranging marks to accumulate.
 3. The ISS need not be on to complete this program unless automatic state vector updating is desired by the Universal Tracking program (P20).
 4. The external Delta V flag is set during this program to designate to the thrusting program that external Delta V steering is to be used.
 5. This program may be selected manually or internally by the MINKEY controller.

Sequence of Events:

If entered automatically by MINKEY controller, go to MANEUVER.

V37E33E P20 Option 0 is activated now.

Note: If P20 rendezvous option is not running, Flashing MINKEY Rendezvous Option Checklist Code 00017

V50N25

PRO Elects MINKEY automatic rendezvous sequencing.

ENTER Elects manual sequencing.

MANEUVER

If the tracking attitude error between the vehicle pointing axis and the LOS to the TARGETING.

LM is less than 10 degrees (computed by P20/R61), go to

Desired FOA angles for	OG(R)	XXX.XX deg
Flashlight	IG(P)	XXX.XX deg
Automanuever	MG(Y)	XXX.XX deg

V50N18

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P33 (continued)

PRO

V06N18 Maneuver in Progress

'f MINKEY sequence, go to TARGETING when maneuver is complete.

Flashing

VSON18 Maneuver Complete (manual sequence)

ENTER Terminates automaneuver routine. Go to TARGETING

Note: P20 (R61) will maintain tracking attitude computations. If the attitude

error becomes greater than 10 degrees, the astronaut will be alerted by:
UPLINK ACTY fight ON

V58E

Request automaneuver execution. Go to MANEUVER.

TARGETING

Flashing

GET of CDH Ignition TIG (CDH)

00x XX h

V06N13

000 XX min

LL ELIPE

0XX. XX s

V25E to correct desired TIG.

PRO

Flashing

Mark Counter (VHF -Optics)

XXbXX

VI6N45,

Time from Ignition TEI (CDH)

XXbXX min/s

MGA

-00001

Mark counter is updated by P20 which may be running in the back

ground.

MGA is only displayed on the final pass.

PRO Set Final flag.

V32E continues in program but Final flag is not set. Used when another pass is desired.

If an Alarm occurs, a V32E may be used to recycle to V06N13 and readjust TIG

If automatic MINKEY sequence, go to Flashing V06N90.

Flashing

Delta Altitude at TIG (CDH)

XXX.XX ami

V06N75,

Delta Time of TIG (CDH/TPI)

XXbXX min/s

Delta Time of TIG (TPI/Nom TPI)

XXbXX min/s

TIG (TPI) is available by keying V06N37E.

PRO

Flashing

Out-of-Plane Position (Y) Active Vehicle

XXX.XX ami

V06N90

Out-of-Plane Velocity (YDOT) Active Vehicle

XXXX.X ft/s

Out-of-Plane Velocity (YDOT) Passive Vehicle XXXX.X ft/s

PRO

Flashing

Delta V at TIG (CDH)

X XXXX.X ft/s

V06N81

in Local Vertical Coordinates

Y XXXX.X ft/s

Z XXXX.X ft/s

PRO

If Final flag is reset go to previous Flashing VI16N45

Flashing

Mark Counter (VHF-Optics)

XXDXX

V16N45

TFI (CDH)

XX_XX min/s

MGA

XXX.XX deg

MGA will be the MGA at TIG (CDH). If the IMU is not aligned, MGA will be
-00002. (For LM solution (P73) MGA is always -00002 on the final pass.)

PRO

If MINKEY controller is active, W-matrix reinitialization is performed and the

```

appropriate burn program is initiated.
  If Delta V solution <7 ft/s, P41 is i
  If Delta V solution 27 ft/s, P40is
  Flashing
v37          Select New Program (manual sequence)

```

P34 - CSM Transfer Phase Initiation (TPI) Targeting

Source PDF pages: 66-68

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P34—CSM TRANSFER PHASE INITIATION (TPI) TARGETING PROGRAM

Purpose:

- 1 To calculate the required Delta V and other initial conditions required by the AGC for execution of the Transfer Phase Initiation maneuver. Given
 - a. TIG (TP!) or the Elevation angle (E) of the CSM/LM LOSat TIG (TPI).
 - b. Central angle of transfer (CENTANG) from TIG (TPI) to intercept time (TIG(TPF)).
 To calculate TIG (TPI) given E or E given TIG (TPI).
 To store the TP! target parameters for use by the desired thrusting program.

Assumptions:

- 1 The program must be done over a tracking station for real-time ground participation in AGC data input and output
 'f P20 is in operation while this program is operating, the astronaut may hold at any flashing display and take optics marks, and/or he may allow VHF ranging marks to accumulate.
 Once the parameters required for computation of the maneuver have been completely specified, the value of the active vehicle central angle of transfer is computed and stored. This number will be available for display to the astronaut through the use of V06 N52.
 The astronaut would call this display to verify that the central angle of transfer of the active vehicle is not within 170 to 190 degrees. If the angle is within this zone the astronaut should reassess the input targeting parameters based upon Delta V and expected maneuver time.
 When determining the initial position and velocity of the target at intercept time, either conic or precision integration may be used. The time difference for computation is approximately 10:1 (that is, conic integration is 10 times faster than precision integration).
 ISS need not be on to complete this program unless automatic state vector updating is desired by the Universal Tracking program.
 The external Delta V flag is reset during this program to designate to the thrusting program that Lambertsteering is to be used.

 The Delta V in LOS coordinates is available in N59.
 This program may be selected manually or internally by the MINKEY controller.

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@
a

CM-66

P34 (continued)

Sequence of Events

i

If entered automatically by MINKEY controller, go to MANEUVER,

V37E34E

Note: If P20 rendezvous option is not running, P20 Option is activated now.

Flashing MINKEY Rendezvous Option

V50N25, Checklist Code 00017

PRO Elects MINKEY automatic rendezvous sequencing.

ENTER Elects manual sequencing.

MANEUVER

If the tracking attitude error between the vehicle pointing axis and the LOS to the LM is less than 10 degrees (computed by P20/R61), go to TARGETING.

Flashing Desired FDAI angles for OG(R) XXX.XX deg

VS50N18 Automaneuver IG{P} XXX.XX deg

MG(Y) XXX.XX deg

PRO

VOGN18 Maneuver in Progress

If MINKEY sequence, go to TARGETING when maneuver is complete.

Flashing

VSON18 Maneuver Complete (manual! sequence)

ENTER Terminates automaneuver routine. Go to TARGETING.

Note: P20 (R61) will maintain tracking attitude computations. If the attitude error becomes greater than 10 degrees, the astronaut will be alerted by: UPLINK ACTY light ON

VS8E

Request automaneuver execution. Go to MANEUVER.

TARGETING

Flashing GET of TPI Ignition TIG (TPI) 00X XX h

V06N37 000XX min

0XX.XX s

V25E to correct desired TIG

PRO

Flashing Number of Precision Offsets 0000 x

V06NS55 Elevation Angle XXX.XX deg

CENTANG XXX.XX deg

V25E to load desired data.

Number of precision offsets is an integration code where X = 0 specifies integration of a conic trajectory to generate the target vector and X # 0 specifies precision integration to generate the target vector. If precision integration is desired, X should equal 2.

Elevation angle is the angle between the CSM/LM LOS and the CSM local horizontal at TIG (TPI). E should = +00000 if E is to be computed at TIG specified.

{For LM solution (P74) the angle is between the LM/CSM LOS and the LM local horizontal.}

CENTANG is the orbital angle traversed by the passive vehicle from TIG (TPI) to time of intercept.

PRO

Flashing Mark Counter (VHF--Optics) XX--XX

V1I6N45, TRI (TPI) XXbXX min/s

MGA at TIG (TPI) -00001

Mark counter is updated by P20 which maybe running in the background.

MGA is -1 until the final pass of the program.

PRO Set Final flag. V32E continues in program but Final flag is not set. Used when another pass is desired.

P34 (continued)

COMPUTE ELEVATION ANGLE FOR GIVEN TIG.
 \f elevation angle above was = 0,

em

Flashing Same as N55 above, except elevation angle has
 V06N55 been computed.
 COMPUTE TIG FOR GIVEN ELEVATION ANGLE. If elevation angle above was #0,

Flashing	Time of Ignition for Specified	00XXX h
V06N37	Elevation Angle TIG (TP1)	000 XX min
		0XX.XXs

If MINKEY FINAL PASS, set E = 0 and go to COMPUTE ELEVATION ANGLE
 FOR GIVEN TIG above.
 Note: If alarm 00611 occurs, PRO to TARGETING at start of program.

PRO	Flashing	Pericenter Altitude (Post-TP!)	nAKX.X nmi
	V06N58	Delta V Required for TPI	XXXX.X ft/s
		Delta V Required for TPF	XXXX.X ft/s
PRO	Flashing	Delta V at TIG (TPI) in	X XXXX.X ft/s
	V06N81	Local Vertical Coordinates	Y XXXX.X ft/s
			Z XXXX.X ft/s

PRO If Final flag is reset, go to previous Flashing V16N45.
 Flashing Mark Counter (VHF -Optics) XXbXX
 V16N45 TFI (TPH) XXbXX min/s
 MGA XXX.XX deg

MGA will be the expected MGA at TIG (TPI). If the IMU is not aligned, MGA will be
 -00002. (For LM solution (P74), MGA is always -00002 on the final pass.)

PRO If MINKEY controller is active, W-matrix reinitialization is performed and the
 1 appropriate burn program is initiated.
 | If Delta V solution <7 ft/s, P41 is
 If Delta V solution 3:7 ft/s, P40is
 Flashing
 V37 Select New Program (manual sequence)

P35 - CSM Transfer Phase Midcourse (TPM) Targeting

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P35—CSM TRANSFER PHASE MIDCOURSE (TPM)
 TARGETING PROGRAM -

Purpose:

- 1, To calculate the required Delta V and other initial conditions required by the AGC for CSM execution of the next midcourse correction of the transfer phase of an active CSM rendezvous.

Assumptions:

1. If P20 is in operation while this program is operating, the astronaut may hold at any flashing display and take optics marks, and/or he may allow VHF ranging marks to accumulate.

Once the parameters required for computation of the maneuver have been completely specified, the value of the active vehicle central angle of transfer is computed and stored. This number will be available for display to the astronaut through the use of V06 N52.

The astronaut would call this display to verify that the central angle of transfer of the active vehicle is not within 170 to 190 degrees. If the angle is within this zone, the astronaut should reassess the input targeting parameters based upon Delta V and the expected maneuver time.

The time of intercept (T(INT)) was defined by previous completion of the Transfer Phase Initiation (TP) program (P-34) and is presently available in AGC storage. ISS need not be on to complete this program unless automatic state vector updating is desired by the Universal Tracking program.

The external Delta V flag is reset during this program to designate to the thrusting program that Lambert steering is to be used.

The Delta V in LOS coordinates is available in N59.

The program may be selected manually or internally by the MINKEY controller.

Sequence of Events:

If entered automatically by MINKEY controller, go to MANEUVER.

V37E35E

Note: If P20 rendezvous option is not running, P20 Option is activated now.

Flashing MINKEY Rendezvous Option

V50N25 Checklist Code

00017

PRO Elects MINKEY automatic rendezvous sequencing.

ENTER Elects manual sequencing.

MANEUVER

If the tracking attitude error between the vehicle pointing axis and the LOS to the LM is less than 10 degrees (computed by P20/R61), go to TARGETING.

Flashing Desired FDAI angles for

OG{R)

XXX.XX deg

V50N18 Automaneuver

1G(P)

XXX.XX deg

MG(Y)

XXX.XX deg

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P35 (continued)

PRO

V06N18 Maneuver in Progress

if MINKEY sequence, go to TARGETING when maneuver is complete.

Flashing

V50N18 Maneuver Complete (manual sequence)

ENTER Terminates automaneuver routine. Go to TARGETING.

Note: P20 (R61) will maintain tracking attitude computations. If the attitude error becomes greater than 10 degrees, the astronaut will be alerted by:

UPLINK ACTylight ON

V58E

Request automaneuver execution. Go to MANEUVER.

TARGETING

	Flashing V16N45	Mark Counters (VHF -Optics) TF (TPM) MGA		XXbXX XXbXX min/s -00001
--	--------------------	--	--	--------------------------------

Mark counter is updated by P20, which may be running in the background.
MGA is -1 until the final pass through program.

PRO SetFinal flag. V32E continues but Final flag is not set. Used when another pass is desired.

	Flashing V06N81	Delta V at TIG (TPM) in Local Vertical Coordinates	x Y Z	XXXX.X ft/s XXXX.X ft/s XXXX.X ft/s
--	--------------------	---	-------------	---

PRO If Final flag is reset, go to previous Flashing V16N45.

	Flashing V16N45	Mark Counter (VHF-Optics) TFI (TPM) MGA		XXbXX XXbXX min/s XXX.XX deg
--	--------------------	---	--	------------------------------------

MGA will be expected MGA at TIG (TPI). If the IMU is not aligned, MGA will be -00002. (For LM solution (P75) MGA is always -00002 on the final pass.)

PRO If MINKEY controller is active, W-matrix reinitialization is performed and the appropriate burn program is initiated.

If Delta V solution < 7 ft/s, P41 is initiated.
If Delta V solution > 7 ft/s, P40 is initiated.

	Flashing V37	Select New Program (manual sequence)		
--	-----------------	--------------------------------------	--	--

P36 - CSM Plane Change (PC) Targeting

Source PDF pages: 71-72

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P36-PLANE CHANGE TARGETING (PC) PROGRAM

Purpose:

1. To calculate parameters associated with the plane change (PC) maneuver for Delta V burns.
2. To store the PC target parameters for use by the desired thrusting program.

Assumptions:

1. This program assumes a stored TIG (CSI) by completion of the Coelliptic Sequence Initiation (CSI) program (P32), an uplinked TIG (CSI) or crew loaded TIG (CSI) in N11,
2. If P20 is in operation while this program is in operation, the astronaut may hold at any flashing display and take optics marks, and/or he may allow VHF ranging marks to accumulate.
3. The ISS need not be on to complete this program unless automatic state vector updating is desired by the Universal Tracking program (P20).
4. This program is normally used to target a plane change burn between CSI and CDH at the midpoint (90 degrees central angle after TIG (CSI)).
5. The external Delta V flag is set during this program to designate to the thrusting program that external Delta V steering is to be used.
6. This program may be selected manually or internally by the MINKEY controller.

Sequence of Events:

If entered automatically by MINKEY controller, go to MANEUVER

V37E36E

Note: If P20 rendezvous option is not running, P20 option is active

Flashing MINKEY Rendezvous Option
V50N25 Checklist Code 00017

PRO Elects MINKEY automatic rendezvous sequencing.
ENTER Elects manual sequencing.
MANEUVER

If the tracking attitude error between the vehicle pointing axis and the LOS to the LM is less than 10 degrees (computed by P20/R61), go to TARGETING

Flashing Desired FDAI angles for
V50N18 Automaneuver

OG(R)	XXX.XX deg
IG(P)	XXX.XX deg
MG(Y)	XXX.XX deg

PRO V06N18 Maneuver in Progress
If MINKEY sequence, go to TARGETING when maneuver is completed.

Flashing
V50N18 Maneuver Complete (Manual Sequence)

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P36 (continued)

ENTER Terminates automaneuver. Go to TARGETING
Note: P20 (R61) will maintain tracking attitude computations. If the attitude error becomes greater than 10 degrees, the astronaut will be alerted by UPLINK ACTY Light On

VS58E Request automaneuver execution. Go to MANEUVER
TARGETING

Flashing GET of PC Ignition TIG (PC)
V06N33 00XX.XX h
000XX min
0XX.XX 5

V25E to modify TIG.

PRO Flashing Mark Counter (VHF -Optics}
VIGN45 Time From Ignition TFI (PC)
MGA XXXbXX
-00001 min/s

Mark Counter is updated by P20 which may be running in the background.
MGA is only displayed on the final pass

PRO Sets Final flag.

V32E Continues in program but Final flag is not set. Used when another pass is desired.

Flashing Out-of-Plane Position (Y) CSM XXX.XX nmi
V06N90 Out-of-Plane Velocity (YDOT) CSM. XXXX.X ft/s
Out-of-Plane Velocity (YDOT) LM XXXX.X ft/s

PRO Flashing Delta V at TIG (PC) X XXXX.X ft/s
V06N81 In Local Vertical Coordinates Y XXXX.X ft/s i
Z XXXX.X ft/s j

V25E to modify Delta V.

PRO If Final flag is reset, go to previous Flashing V16N45.

Flashing Mark Counter (VHF -Optics) XXPXX
V16N45 TEI (PC) XXbXX min/s

```

                                MGA                                XXX.XX deg
MGA will be the MGA at TIG (PC). If the IMU is not aligned, MGA will be -00002
PRO If Manual Sequence, go to Flashing V37
If MINKEY controller is active, W-matrix reinitialization is performed and Delta V
(N81) magnitude is tested:
    if OV magnitude = 0, MINKEY initiates P76

a      If DV magnitude > 0, MINKEY initiates P52 for possible realignment to
|      new orientation to avoid gimbal lock for + X-axis burn. Go to P52
|      (PC Realign)
|      Note: Crew may elect to perform a Y-axis RCS burn, if the Delta V is small, to
|      bypass realigning the IMU. This option is available in P52 (PC Realign).
I      If the IMU is reoriented for a PC maneuver, it is returned to its original
'|     orientation by P52 as controlled by the MINKEY sequencer.
|
|      Flashing
{      v37          Select New Program (manual sequence)
4
|
|

```

P37 - Return to Earth

Source PDF pages: 73-74

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CM-72

P37-RETURN TO EARTH

Purpose:

providing the CSM is outside

1. This program will compute a return-to-earth trajectory the lunar sphere of influence at the time of ignition.

meters based on a

2. This program computes and displays a preliminary series of parabolic conic trajectory and:
 - a. Astronaut specified time of ignition.
 - b. Astronaut specified maximum change in velocity.
 - c. Astronaut specified reentry angle.

These parameters are:

Time from ignition to reentry.

ea00e

Reentry inertial velocity.

Reentry flight path angle.

Latitude of splash.

Longitude of splash.

- f. Delta V (LV).

recomputes the

3. When the initial display is satisfactory to the astronaut, the program recomputes the same data, using applicable perturbations to the conic trajectory new values, and displays the

stores the target

4. Upon final acceptance by the astronaut, the program computes and stores the target parameters for return to earth for use by the SPS program (P40) or RCS program

(P41).

d:

5. Based upon the specified propulsion system the following are displayed:
- Middle gimbal angle at ignition (MGA).
 - Time of ignition (TIG).
 - Time from ignition (TFI).

Assumptions:

is completely

- This program assumes that contact with the ground is unavailable, and self-contained.
- If value of VPRED entered in Noun 60 is less than the minimum required to return to earth, the Delta V required vector will be computed based on a minimum value. If the value entered is greater than the minimum required to return to earth, then the astronaut desired value will be used to compute the Delta V required vector. The computed Delta V required vector will be displayed in Noun 81.
- The DAP Data Load routine (R03) should be performed prior to completion of this program.
- The reentry range calculation provided by the AU GE KU GE L routine may be overwritten by a pad loaded single precision erasable.
- The external Delta V flag is reset during this program to designate to program that Lambert steering is to be used.

the thrusting

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P37 (continued)

Sequence of Events:

V37E37E

Flashing	GET of RTE	Ignition TIG (RTE)	00X XX h
V06N33			000 XX min
			0XX.XX s

V25E to load desired TIG.

PRO

Flashing	Blank	—
V06N60	VPRED	XXXXX. ft/s
	GAMMA EL	XXX.XX deg

V25E to load desired data.

VPRED is the maximum allowable velocity change for RTE. Zero is entered to compute the minimum AV to conserve fuel. See Assumption 2. GAMMA EL is the desired flight path angle between the inertial velocity vector and the local horizontal at Entry Interface (E1) altitude of 400,000 ft.

PRO

Flashing	Impact Latitude	XXX.XX deg (+ north)
V06N61	Impact Longitude	XXX.XX deg (+ east)

To change the desired landing site longitude the maximum velocity change (VP RED) input is adjusted. The AGC-calculated minimum Vg is available by keying V06N40(R2). Increasing this value and entering it (t) into VPRED will move the longitude (-) west or (+) east. To adjust input parameters, key V32E and recycle to V06N33.

PRO

Flashing	'Transfer Time from TIG (RTE)	00X XX h
----------	-------------------------------	----------

	V06N39	to El	000Xx min 0XX.XX s
PRO	To changetransfer time. V32E to recycle to V06N33andreadjust input parameters.		
	Flashing V06N60	Blank VPRED GAMMA EL	XX XXX ft/s XXX.XX deg
PRO	VPRED is the predicted inertial velocity at Entry Interface (El). V32 to recycle to V06N33		
	Flashing V06N81	Delta V at TIG (RTE) in Local Vertical Coordinates	XXXX.X ft/s XXXX.X ft/s XXXX.X ft/s
PRO	If first pass through program recycle to Flashing V06N61.		
	Flashing V04N06	Option Code {specify propulsion system) Propulsion Code (1-SPS, 2-RCS)	00007 0000x
PRO	V22Eto load desired option.		
	Flashing V06N33	GET of RTEIgnition TIG (RTE)	00xxx h 000XX min 0XX.XXs
PRO	Flashing V16N45	Mark Counter (VHF -Optics) TRI (RTE) MGA	Not meaningful XXbXX min/s XXX.XX deg
	MGA will be the middle gimbal angle at TIG or -00002 if the IMU is not aligned.		
PRO	Flashing v37	Select New Program.	

P40 - SPS

Source PDF pages: 75-76

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CM-74

P40-SPS PROGRAM

Purpose:

- 1 To compute a preferred IMU orientation and a preferred vehicle attitude for an SPS. thrusting maneuver and to maneuverthe vehicle to the thrusting attitude.
 - 2 To calculate and display the gimbal angles which would result from the present IMU orientation if the vehicle were maneuvered to the preferred vehicle attitude for an SPS thrusting maneuver. The crew is thereby given an opportunity to perform the maneuver with:
 - a. The present IMU orientation (not recommendedif middle gimbal angle is greater than 45 degrees). If the IMU has not been aligned within the last 3 hours, realignment is desirable.
 - b. A neworientation achieved by selection of P52
- To control the GNCS during countdown, ignition, thrusting, and thrust termination of a GNCS controlled SPS maneuver.

Assumptions:

1. The target parameters have been calculated and stored in the AGC by prior execution of a prethrusting program.
The required steering equations are identified by the prior prethrust program, which either set or reset the external Delta V steering flag. For external Delta V steering, VG is calculated once for the specified time of ignition. Thereafter, both during thrusting and until the crew notifies the AGC trim thrusting has been completed, the

AGC updates VG only as a result of compensated accelerometer inputs. For Lambert steering, VG is calculated and updated similarly; however, it is also updated periodically by Lambert solutions to correct for changes in the CSM state vector.

The TTE clock is set to count to zero at TIG.

Engine ignition may be slipped beyond the established TIG if desired by the crew or if integration can not be completed on time.

The SPS thrusting program does not monitor the SC control discrete (Channel 31, Bit 15) during thrusting. This means that the AGC will continue to generate engine actuator commands, SPS Engine On discrete, and FDA! attitude error needle commands until the AGC solution indicates Engine Off at which time these commands and the Engine On discrete are terminated. However, this program is not written to take into account the situation where control may be taken away from the GNCS and then given back, and it is not recommended. In event control is taken away from the GNCS, the AGC will only be responsible for computation of position and velocity.

The value of Delta V required will be stored in the local vertical coordinate system and is available during this program until average g turn-on by keying in V06 N81E. The Orbit Parameter Display routine (R30) may be called during this program by keying in V82E.

8. This program may be selected manually or internally by the MINKEY controller.

Sequence of Events:

If entered automatically by MINKEY controller, go to Flashing VS0N18.
Maneuver to pad burn attitude and check SXT and boresight stars using optics angles on pad.

V37E40E

Flashing	Desired FDA! Angles for	OG(R)	XXX.XX deg
V50N13	Automaneuver	1G(P)	XXX.XX deg
		MG(Y)	XXX.XX deg

Request maneuver to computed burn attitude

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P40 (continued)

PRO

V06N18 Same as N18 above.

Maneuver is in process; final FDAI angles displayed.

Flashing Same as N18 above.

VS50N18 Automaneuver is completed.

SCS-GDC aligned to IMU for backup attitude reference.

SPS gimbal drive motors energized.

S/C Control to SCS; SPS servo check and manual drive check performed.

S/C Control to CMC.

PRO

Flashing Same as N18 above.

V50N18 Vehicle is trimmed to burn attitude.

ENTER

Flashing Gimbal Slew Test Option.

V50N25 Checklist Code

00204

PRO SLEWS SPS gimbal 2 degrees; ENTER – Bypasses gimbal slew test.

SPS gimbals commanded to trim angles (P, Y)

V06N40 Time from Ignition/Cutoff (TF!)

XXbXX min/s

Velocity to be Gained (Vg)

XXXX.X ft/s

Accumulated Velocity (AV)XXXX.X ft/s

DSKY blanks at TIG - 35 seconds, and V06N40 resumes at TIG -30 seconds.

Average G on.

Ullage initiated with THC if required.

Flashing

Same as N40 above at TIG -5 seconds.

V99N40

Astronaut approval of ignition requested.

PR0

Ignition approved.

V06N40

Same as N40 above.

Ignition at TIG.

TVC DAP activated.

SPS engine cutoff; burn complete.

TVC DAPoff.

Flashing

Same as N40 above.

V16N40

PR0

Flashing

Vg Residuals in Control

X XXXX.X ft/s

Vi6N85

System (body) Coordinates

Y XXXX.X ft/s

Z XXXX.X ft/s

TRIM Vg residuals with THC if required.

PR0 If MINKEY controller is active, P76 is entered.

Flashing

V37

(Manual Sequence)

| V82E Request orbital parameter display.

{

Flashing

Apocenter Altitude, Ha

XXXX.X ami

V1I6N44

Pericenter Altitude, Hp

XXXX.X nmi

TFF

XXbXX min/s

PR0

Flashing

Select New Program.

Vv37

; Average G off.

|'

ccalaan

P41 - RCS

Source PDF pages: 77-78

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CM-76

P41-RCS PROGRAM

Purpose:

1.

Compute a preferred IMU orientation and preferred vehicle attitude for an RCS thrusting maneuver and to maneuverthe vehicle to the thrusting attitude.
2.

Calculate the gimbal angles which would result from the present IMU orientation if the vehicle +X axis were aligned to the thrust vector. The crew is thereby given an opportunity to perform the maneuver with:

a.

The present IMU orientation (not recommendedif middle gimbal angle is greater than 45 degrees). If the IMU has not been aligned within the last 3 hours, realignment is desirable.

b.

A new orientation achieved by selection of P52.
3.

Provide suitable displays for manual execution of the thrusting maneuver.

Assumptions:

1.

The target parameters have been calculated and stored in the AGC by prior

- execution of a prethrusting program.
2. The required steering equations are identified by the prior prethrust program, which either set or reset the external Delta V steering flag. For external Delta V steering, VG is calculated once for the specified time of ignition. Thereafter, both during thrusting and until the crew notifies the AGC trim thrusting has been completed, the AGC updates VG only as a result of compensated accelerometer inputs. For Lambert steering, VG is calculated and updated similarly. However, it is also updated periodically by Lambert solutions to correct for changes in the CSM state vector.
 3. The TTE clock is set to count to zero at TIG.
Translation initiation may be slipped beyond the established TIG if desired by the crew or if integration cannot be completed on time.
 5. The value of Delta V required will be stored in the local vertical coordinate system and is available during this program until Average G turn-on by keying in V06 N81E.
 6. The Orbit Parameter Display routine (R30) may be called during this program by keying in V82E.
 7. This program may be selected manually or internally by the MINKEY controller.

Sequence of Events:

\f entered automatically by MINKEY controller, go to Flashing V50N18.
Maneuver to pad burn attitude and check SXT and boresight stars using optics angles on pad.

V37E41E

Flashing	Desired FDA! Angles	OGIR)	XXX.xx deg
V50N18		IG(P)	XXX.XX deg
		MG(Y)	XXX.XX deg

Request maneuver to computed burn attitude.

PRO

V06N18	Same as N18 above.
Auto maneuver in process; final FDA! angles displayed.	
Flashing	Same as N18 above. Maneuver is complete.
V50N18	

ENTER

V16N85	Velocity to be Gained in Control	x	XXXX.X ft/s
	System (body) Coordinates (Vg)	Y	XXXX.X ft/s
		Z	XXXX.X ft/s

OSKY blanks at TIG -35 seconds and resumes display at TIG -30 seconds.

Average G on at TIG -30 seconds.

Flashing	Flash signifies T!IG has arrived.
V16N85	Same as N85 above.

Null Vg with THC at TIG.

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P41 (continued)

PRO If MINKEY controller is active, P76 is entered.

Flashing	
V37	(Manual Sequence)

V82E Request Orbital Parameter display.

Flashing	Apocenter Altitude	XXXX.X ft/s
V16N44	Pericenter Altitude	XXXX.X ft/s
TFF		XXbXX min/s

PRO

Flashing

V37

Average G off.

Select New Program.

P47-THRUST MONITOR PROGRAM

Purpose:

1.

2.

To monitor vehicle acceleration during a non-GNCS-controlled thrusting maneuver.

To display the Delta V applied to the vehicle by this thrusting maneuver.

Assumptions:

1.

2.

3.

4.

6.

This program is normally used during rendezvousfinal phase. lf the crew desires to do any final phase thrusting maneuvers automatically under GNCScontrol, they must be accomplished via selection of the Transfer Phase Initiation (TP1) program (p34) and then the SPS Thrusting program (P40) or the RCS Thrusting program P41).

Range, Range Rate, and Theta may be displayed during this program bycalling the Rendezvous Parameter Display routine No. 1 (R31) with V83E.

Range, Range Rate, and Phi may be displayed during this program bycalling the Rendezvous Parameter Display routine No. 2 (R34) with V85E.

V1, H, and H-dot maybe called by keying in V16 N62E.
The Orbit Parameter Display routine may be called during this program by keyingin V82E.

This program should be turned on just prior to the planned thrusting maneuver and terminated as soon as possible following the maneuverin order to keeperrors of bias and AVERAGE G at a minimum.

Sequence of Events:

V37E47E

Flashing

V16N83

Delta V Accumulated in Control

Coordinate System

x

Y

Zz

XXXX.X ft/s

XXXX.X ft/s

XXXX.X ft/s

Display of integrated acceleration during thrusting.

OPTIONAL DISPLAYS

V16N62E

Crew Optional Display

V16N62

Magnitude of Inertial Velocity (V1)

Rate of Change of Altitude (HDOT)

Altitude Above Pad Radius (H)

XXXXX. ft/s

XXXXX. ft/s

XXXX.X am

IER "

P47 - Thrust Monitor

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P41 (continued)

PRO

If MINKEY controller is active, P76 is entered.

Flashing

V37

(Manual Sequence)

V82E Request Orbital Parameter display.

Flashing

Apocenter Altitude

XXXX.X ft/s

V16N44

Pericenter Altitude

XXXX.X ft/s

TFF

XXbXX min/s

PRO

Flashing

Select New Program.

V37

Average G off.

P47-THRUST MONITOR PROGRAM

- Purpose:
1.

To monitor vehicle acceleration during a non-GNCS-controlled thrusting maneuver.
2.

To display the Delta V applied to the vehicle by this thrusting maneuver.

- Assumptions:
1.

This program is normally used during rendezvousfinal phase. lf the crew desires to do any final phase thrusting maneuvers automatically under GNCScontrol, they must be accomplished via selection of the Transfer Phase Initiation (TP1) program (p34) and then the SPS Thrusting program (P40) or the RCS Thrusting program P41).
2.

Range, Range Rate, and Theta may be displayed during this program bycalling the Rendezvous Parameter Display routine No. 1 (R31) with V83E.
3.

Range, Range Rate, and Phi may be displayed during this program bycalling the Rendezvous Parameter Display routine No. 2 (R34) with V85E.
4.

V1, H, and H-dot maybe called by keying in V16 N62E.
The Orbit Parameter Display routine may be called during this program by keyingin V82E.
6.

This program should be turned on just prior to the planned thrusting maneuver and terminated as soon as possible following the maneuverin order to keeperrors of bias and AVERAGE G at a minimum.

Sequence of Events:

V37E47E

Flashing

Delta V Accumulated in Control

x

XXXX.X ft/s

V16N83

Coordinate System

Y

XXXX.X ft/s

Zz

XXXX.X ft/s

Display of integrated acceleration during thrusting.

OPTIONAL DISPLAYS

V16N62E

Crew Optional Display

V16N62

Magnitude of Inertial Velocity (V1)

XXXXX. ft/s

Rate of Change of Altitude (HDOT)

XXXXX. ft/s

Altitude Above Pad Radius (H)

XXXX.X ami

IER "

KEY REL

Flashing Same as N83 above.
V16N83

V83E Rendezvous parameter display at crew option.

Flashing Range of CSM to LM XXX.XX ami
V16N54 Range Rate XXXX.X ft/s
Angle Between CSM +X Axis and
Local Horizontal (Theta) XXX.XX deg

PRO

V85E Rendezvous parameter display at crew option.

Flashing Range of CSM to LM XXX.XX ami
V16N53 Range Rate XXXX.X ft/s
Angle Between Optics SLOs and the
Local Horizontal (PH!) XXX.XX deg

PRO

V82E Orbital parameter display.

Flashing Apocenter Altitude XXXX.X nmi
V16N44 Pericenter Altitude XXXX.X ami
TFF XXbXX min/s

PRO

Flashing Same as N83 above.
V16N83

PRO

Flashing Select New Program.
V37

Average G off.

P51-IMU ORIENTATION DETERMINATION PROGRAM

Purpose:

1. To determine the inertial orientation of the IMU using sightings on two celestial bodies using the scanning telescope or the sextant.

Assumptions:

1. Time and RCS fuel may be saved, and subsequent IMU alignment decisions greatly simplified if this program is performed in such a way as to leave the IMU inertially stabilized at an orientation as close as possible to the optimum orientation required by future AGC programs.

P51 - IMU Orientation Determination

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P47 (continued)

KEY REL

Flashing Same as N83 above.
V16N83

V83E Rendezvous parameter display at crew option.

Flashing Range of CSM to LM XXX.XX ami
V16N54 Range Rate XXXX.X ft/s

		Angle Between CSM +X Axis and Local Horizontal (Theta)	XXX.XX deg
PRO			
V85E	Rendezvous parameter display at crew option.		
	Flashing	Range of CSM to LM	XXX.XX ami
	VI6N53	Range Rate	XXXX.X ft/s
		Angle Between Optics SLOs and the Local Horizontal (PH!)	XXX.XX deg
PRO			
V82E	Orbital parameter display.		
	Flashing	Apocenter Altitude	XXXX.X nmi
	VI6N44	Pericenter Altitude	XXXX.X ami
		TFF	XXbXX min/s
PRO			
	Flashing	Same as N83 above.	
	VI6N83		
PRO			
	Flashing	Select New Program.	
	V37		
	Average G off.		

P51-IMU ORIENTATION DETERMINATION PROGRAM

Purpose:

1. To determine the inertial orientation of the IMU using sightings on two celestial bodies using the scanning telescope or the sextant.

Assumptions:

1. Time and RCS fuel may be saved, and subsequent IMU alignment decisions greatly simplified if this program is performed in such a way as to leave the IMU inertially stabilized at an orientation as close as possible to the optimum orientation required by future AGC programs.

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P51 (continued)

Sequence of Events:

V37E51E	Flashing	Checklist Code	00015
	V50N25	Perform Celestial Body Acquisition	
ENTER	To Bypass Coarse Align PRO to Flashing V51.		
	Flashing	Desired Gimbal Angles to	OG 000.00 deg
	V41N22	Coarse Align to	IG 000.00 deg
			MG 000.00 deg

No Att light on.

No Att light off when coarse align complete.

Flashing

V51

Request mark.

ZERO OPTICS for 15 seconds.

OPTICS Mode – Manual

MARK

Flashing	Checklist Code	00016
V50N25	Request terminate mark sequence.	
MARK REJECT and recycle to Flashing V51 if not satisfactory.		

PRO

Flashing	Celestial Body Code	000 XX
V0IN71	00-planet, 01/45-star,	
	46-sun, 47-earth, 50-moon	

V21E load correct star code.

PRO If Star Code # 0 and first mark, recycle to Flashing V51.

{f Star Code # 0 and second mark, go to Flashing V06N05.

Flashing	Unit Vector Specifies Planet	x	-XXXXX
V06N88	Position	Y	-XXXXX
		Z	-XXXXX

V25E to load planet vector.

PRO If first mark, recycle to Flashing V51.

Flashing	Star Angle Difference*	XXX.XX deg
V06N05		

PRO V32E to recycle to start of program.

REFSMMAT flag set.

Flashing	Select New Program.
V37	

*Acceptable NOS Limits

STAR/STAR	SXT_ 0.03,
	SCT 0.110
STAR/PLANET	SXT 0.18,
	SCT 0.21

P52 - IMU Realign

Source PDF pages: 81-84

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P52-IMU REALIGN PROGRAM

Purpose:

1. To align the IMU from a "known" orientation to one of four orientations selected by the astronaut using sightings on two celestial bodies with the scanning telescope or the sextant
 - a. Preferred Orientation (00001)

An optimum orientation for a previously calculated maneuver. This orientation must be calculated and stored by a previously selected program or previously uplinked via P27
 - b. Landing Site Orientation (00004)

$X_{gm} = \text{Unit} (R_g)$
 $Y_{gm} = \text{Unit} (Z_{gm} * X_s)$
 $Z_{sm} = \text{Unit} (H_{osm} \times X_{sm})$

where

Theor_{igin} is the center of the moon
 = The position of the most recently defined landing site at time T (align)
 eehSited by the astronaut.
 Hcog_m = The angular momentum vector of the CSM ($R_{ogm} \times V_{csm}$) at
 timeT (align) selected by the astronaut.

The landing site option is used for aligning the CSM and LM stable members to the same orientation prior to LM/CSM separation and prior to LM ascent from

the lunar surface.

c. Nominal Orientation (00002)

$X_{gm} = \text{Unit } (Y_{su} \times Z_{sm})$

$Y_{gm} = \text{Unit } (V \times A)$

$Z_{gm} = \text{Unit } (-R)$

where

R = The geocentric (earth orbit) or selenocentric (lunar orbit) radius vector at time T (align) selected by the astronaut.

V = the inertial velocity vector at time T (align) selected by the astronaut.

d. REFSMMAT (00003)

The present IMU orientation differs from that to which it was last aligned due to gyro drift. This option realigns the IMU to its previous alignment orientation (REFSMMAT).

2. To align the IMU to a predetermined orientation suitable for a plane change (PC) maneuver and to realign the IMU after the maneuver to the pre-PC orientation.

$X_{gmi} = \text{Unit } (X_{gmo} \cos 45^\circ + Y_{sqo} \sin 45^\circ)$ for first maneuver

$X_{go} = \text{Unit } (X_{gmo} \cos 45^\circ - Y_{gmo} \cos 45^\circ)$ for second maneuver

$Y_{om} = \text{Unit } (25m \times X_{su})$

$2_{sm} = 2_{smo}$

where subscript '0' refers to the orientation existing before the alignment.

Assumptions:

1. If the CMC Mode switch is in CMC-Attitude Hold during the Gyro Torquing routine (R55), the DAP will maneuver the vehicle to follow the platform.
2. An option is provided to point the sextant LOS at astronaut or AGC selected stars either manually by crew input or automatically under AGC control.
3. This program may be selected manually or internally by the MINKEY controller in conjunction with the plane change maneuver.

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P52 (continued)

Sequence of Events

If entered automatically by MINKEY controller, go to PC REALIGN

V37E52

Flashing

Option 1D Code

~

00001

V04N06

Alignment Option

0000x

1--preferred, 2--nominal

3--REFSMMAT, 4--landing site

V22E to key in desired alignment option.

PRO To appropriate option.

PC REALIGN

Flashing

Gimbal angles which will

OG

XXX.XX deg

V06N22

result from pulse torque to

1G

XXX.XX deg

PC orientation

MG

XXX.XX deg

If MGA is not satisfactory, maneuver vehicle and V32E to recompute N22 angles

PRO If N22 angles are satisfactory.

Flashing

MINKEY Pulse Torque Option

VSON25

Checklist Code

00020

ENTER If this is first reorientation maneuver, the pulse torque to PC orientation is bypassed and MINKEY enters the RCS Burn program (P41). If this is the second reorientation maneuver, alarm 00402 is displayed. The platform must be torqued to its original orientation.

PRO Commence with pulse torquing.

V16N20	Present ICDU Angles	OG	XXX.XX deg
		IG	XXX.XX deg
		MG	XXX.XX deg

Upon completion of pulse torquing to new orientation, the MINKEY controller will initiate:

1. P41 if pre-plane change burn and if $\Delta V < 7$ ft/s
2. P40 if pre-plane change burn and if $\Delta V > 7$ ft/s
3. P33 if plane-change maneuver completed (second pulse torque)

LANDING SITE OPTION (00004)

Flashing	GET of Landing Site Coordinate	00XXX h
V06N34	System T(Align)	000 XX min
		0XX.XX s

V25E to load desired T(Align).

PRO

	Flashing		
	V06N89		
		Latitude of Landing Site	
		Longitude/2	
			XX.XXX deg (+ north)
			XX.XXX deg (+ east)
		Altitude	XXXK.XX nmi

V25E to load landing site coordinates.

PRO To Preferred Option

NOMINAL OPTION (00002)

Flashing	Same as N34 above, except GET of position and
V06N34	velocity vectors defining nominal coordinate system

PRO To Preferred Option

PREFERRED OPTION (00001)

Flashing	Desired Gimbal Angles for New	OG	XXX.XX deg
V06N22	Orientation at Present Vehicle	IG	XXX.XX deg
	Attitude	MG	XXX.XX deg

If the new orientation yields gimbal lock, maneuver vehicle and V32E to recompute (N22) desired gimbal angles.

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PS2 (continued)

PRO

Flashing	Coarse Align Option™	
V50N25	Checklist Code	00013

CMC Mode Switch – FREE

{Avoids maneuvering vehicle) – Key in ENTER or PRO

Gyro Torque Only

ENTER

Torques gyros to achieve new orientation (maintains attitude reference).

V16N20	Monitor Gimbal Angles	OG	XXX.XX deg
		IG	XXX.XX deg
		MG	XXX.XX deg

Go to RECHECK when torquing is complete

Coarse Align Only

PRO Coarse aligns gimbals to achieve new orientation (lose attitude reference)
 No Att light ON until coarse align complete.
 Go to REFSMMAT option when No Att fight out.

REFSMMAT OPTION (00003)

Flashing	Checklist Code	00015
V50N25		

Request Celestial Body acquisition

PRO AGC will select two available stars. Use ENTER to specify crew selection of stars.

MARK SEQUENCE

Flashing	Star 1D Code	000 Xx
V01N70		

V21E to key in star code.

ZERO OPTICS for 15 seconds.

OPTICS Mode – CMC

PRO For Planet XX = 00; if XX # 00, go to V06N92 display.

Flashing	Unit Vector Specifies	x	.XXXXX
V06N88.	Planet Position	Y	XXXXKX
		Zz	XXXXX

V22E to specify desired planet vector.

PRO	V06N92	Desired Optics Angles		
			Shaft	XXX.XX deg
			Trunnion	XX.XXX deg

CMC drives optics LOS to target.

OPTICS Mode – Manual

Flashing	Request Mark
Vv51	

Mark on Target

Flashing	Checklist Code	00016
VSON25		

Terminate Mark Sequence option

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CM-83

-

see

P52 (continued)

~

PRO	Marking was okay, if not MARK REJECT.	
	Flashing	Star 1D Code of Body
	V01N71	Marked On
		000 XX

V21EXXE if not correct.

PRO \f Star Code # 0 and first MARK, recycle to Mark sequence.

\f Star Code 4 0 and second MARK, go to Flashing V06N05.

Flashing	Same as N88 above.
V06N88	

V25E to correct planet vector.

PRO \f first MARK recycle to MARK sequence.

Flashing	Star Angle Difference*	XXX.XX deg
V06N05		

If NOS not satisfactory, V32E, and go to RECHECK.

PRO	Flashing	Gyro Torque Angles to Fine Align	X	-XX.XXX deg
	V06N93		Y	XX.XXX deg
			Z	--XX.XXX deg

CMC Mode Switch – Free (Avoids maneuvering vehicle when torquing gyros).

PRO Torque gyros. V32E to bypass gyro torquing.

RECHECK

Flashing Checklist Code 00014

V50N25 Fine Alignment Option

PRO Recycles to REFSMMAT option for check on alignment.

ENTER

Flashing Select New Program.

V37

*Acceptable NOS Limits

° 0 00

STAR/STAR	SXT	0.03
	SscT	0.11
STAR/PLANET	SXT	0.18
	scT	0.21

P53 - Backup IMU Orientation Determination

Source PDF pages: 85

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CM-84

M

P53-BACKUP IMU ORIENTATION DETERMINATION PROGRA

Purpose:

14. To determine the inertial orientation of the IMU using a backup optical device.

Assumptions:

1. This program is identical to P51 except that R56 is called in place of R53. nment decisions greatly

2, Time and RCS fuel may be saved and subsequent IMU alig leave the IMU inertially

simplified if this program is performed in such a way as to ntation required

stabilized at an orientation as close as possible to the optimum orie

by future AGC programs.

Sequence of Events:

V37E53E

Checklist Code 00015

Flashing

V50N25 Perform Celestial Body acquisition.

ENTER To bypass coarse align, PRO to Flashing V06N94.

Flashing

Desired Gimbal Angles OG XXX.XX

to Coarse Align to IG XXX.XX

V41N22

MG XXX.XX

No Att light on.

te.

No Att light off when coarse align comple

Optics Angle Coordinates Shaft XXX.XX deg

Flashing

V06N94

for Alternate LOS

Trunnion XX.XXX deg

PRO

V24E to load LOS coordinates.

ENTER

Flashing Request Mark.

V53

Does alternate LOS mark.

Checklist Code

00016

Flashing

VS50N25

Terminate Mark Sequence

V53.

PRO

Key ENTER to reject mark and recycle to Flashing

Flashing Celestial Body Code

000 Xx

V0IN71

V21E to load star code.

PRO.

If Star Code # 0 andfirst mark, recycle to Fla

lf Star Code # 0 and second mark, go to Flashing V06N05.

Unit Vector Specifies

x

-XXXXX

Flashing

V06N88

Planet Position

Y

-XXKXX

Zz

XXXXXX

PRO

V25E to load planet vector.

If first mark, recycle to Flashing V06N94.

Star Angle Difference"

XXX.XX deg

Flashing

V06N05

PRO

V32E to recycle to start of program.

Set REFSMMAT flag.

Flashing

V37

Select New Program.

"Acceptable N05 Limits

STAR/STAR

COAS 0.707

STAR/PLANET

COAS 0.72

P54 - Backup IMU Realign

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CM85

P54–BACKUP IMU REALIGN PROGRAM

- Purpose:
14. To align the IMU from a "known" orientation to one of four orientations selected by the astronaut using sightings on two celestial bodies with a backup optical device:

a. Preferred Orientation (00001)

An optimum orientation for a previously calculated maneuver. This orientation must be calculated and stored by a previously selected program or previously uplinked via P27.

b. Landing Site Orientation (00004)

Xgm = Unit (Rus)

Ygm = Unit (Zum x Xs)

Zsgm = Unit (Hosm x Xs)

where

The origin is the center of the moon.

Ris = The position of the most recently defined landing site at time T (align) selected by the astronaut.

Hosm = The angular momentum vector of the CSM ($R_{csm} \times V_{csm}$) at time T (align) selected by the astronaut.

The Landing Site option is used for aligning the CSM and LM stable members to the same orientation prior to LM/CSM separation and prior to LM ascent from the lunar surface.

c. Nominal Orientation (00002)

$X_{gm} = \text{Unit}(Y_{sm} * Z_{sm})$

$Y_{gm} = \text{Unit}(V \times R)$

$Z_{sm} = \text{Unit}(-R)$

where

R = The geocentric (earth orbit) or selenocentric (lunar orbit) radius vector at time T (align) selected by the astronaut.

V = The inertial velocity vector at time T (align) selected by the astronaut.

d. REFSMMAT (00003)

The present IMU orientation differs from that to which it was last aligned due to gyro drift. This option realigns the IMU to its previous alignment orientation (REFSMMAT).

Assumptions:

Torquing routine

1. If the CMC Mode switch is in CMC-Attitude Hold during the Gyro (R55), the DAP will maneuver the vehicle to follow the platform.
2. This program is identical to P52 except that R56 is called in place of R52 and R53.

Sequence of Events:

V37E54E

Flashing	Option 1D Code	00001
V04N06	Alignment Option	0000 Xx
	1--preferred, 2--nominal,	
	3--REFSMMAT, 4--landingsite.	

PRO To appropriate option.

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P54 (continued)

LANDING SITE OPTION (00004)

Flashing	GET of Landing Site Coordinate	000X XX h
V06N34	System T(Align)	000 XX min
		0XX.XX s

V25E to load desired T(Align).

PRO

Flashing	Latitude of Landing Site	XX.XXX deg (+ north)
V06N89	Longitude/2	XX.XXX deg (+ east)
	Altitude	XXX.XX am

V25E to load landingsite coordinates.

PRO To Preferred option.

NOMINAL OPTION (00002)

Flashing V06N34 Same as N34 above except GET of position and velocity vectors defining nominal coordinate system.

PRO ToPreferred option.
PREFERRED OPTION (00001)

Flashing V06N22 Desired Gimbal Angles for New Orientation at Present Vehicle Attitude

OG XXX.XX deg
IG XXX.XX deg
MG XXX.XX deg

If the new orientation yields gimbal lock, maneuver vehicle and V32E to recompute (N22) desired gimbal angles.

PRO

Flashing V50N25 Checklist Code Coarse Align Option 00013

CMC Mode switch – Free (avoids maneuvering vehicle). Key in ENTER or
PRO

ENTER
Torques gyros to achieve new orientation (maintains attitude reference).

V16N20 Monitor Gimbal Angles

OG XXX.XX deg
IG XXX.XX deg
MG XXX.XX deg

Go to RECHECK when torquing is complete.

PRO Coarse aligns gimbal to achieve new orientation (loses attitude reference).
No Attlight - on.
No Att light - off when coarse align is complete, go to REFSMMAT option.

REFSMMATOPTION (00003)

Flashing V50N25 Checklist Code 00015

Request Celestial Body acquisition.

PRO AGC will select two available stars. Use ENTER to specify crew selection of stars.

MARK SEQUENCE

Flashing V01N70 Star 1D Code 000 XX

V21E to load star code.

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P54 (continued)

PRO If Star Code #0, go to Flashing V06N94.

Flashing V06N88 Unit Vector Specifies Planet Position

x XXXXX
Yy .XXXXXX
Zz XXXXX

V25E to load desired planet vector

PRO

Flashing V06N94 Optics Angles for Alternate LOS

i Shaft XXX.XX c
i Trunnion XX.XXX

V24E to load LOS coordinates..

PRO

Flashing V83 Request Mark

ENTER
Does alternate LOS mark

Flashing VS50N25 Checklist Code Terminate Mark Sequence 00016

```

PR0   Key ENTER to reject MARK and recycle to Flashing V53.
      Flashing      Celestial Body Code of Body      000 Xx
      V01N71        Marked On
      V21€ to correctstar code.

PR0   If Star Code #0 andfirst mark, recycle to Mark Sequence.
      If Star Code #0 and second mark, go to Flashing V06N05
      Flashing      Same as N88 above.
      V06N88
      V25E to correct planet vector.

PR0   If first mark, recycle to Mark Sequence.
      Flashing      Star Angle Difference"          XXX.XX
      V06N05

PR0   If NOS unsatisfactory, V32E and go to RECHECK
      Flashing      Gyro Torque Anglesto Fine Align    X   _XX.XXX
      V06N93        Y   XX.XXX
      Zz   XX. XXX

CMC Mode Switch – Free
      (Avoids maneuvering vehicle when torquing gyros.)
PR0 Torques gyros. (V32E to bypass gyro torquing.)
RECHECK
      Flashing      Checklist Code      00014
      V50N25        Fine Alignment Option

PR0 Recycles to REFSMMAT option for check on alignment.
ENTER
      Terminate Program
{      Flashing      Select New Program
|      v37
}
i   *Acceptable NOS Limits
|   STAR/STAR      cOAS 0.70,
|   STAR/PLANET    COAS 0.72

```

P61 - Entry - Preparation

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P61--ENTRY--PREPARATION PROGRAM

Purpose:

- To start navigation, check !MU alignment, and Pro vide entry monitor system initialization data.

Assumptions:

- The program is entered with adequate freefall time to com plete the maneuvers from a worstcase starting attitude.
- The ISS is on and precisely aligned to a satisfactory orientat ion.

Sequence of Events:

V37E61E

```

      Average G On
      Flashing      Impact Latitude      XXX.XX deg
      V06N61        Impact Longitude     XXX.XX deg
      Roll Attitude Code      +0000x
      X = +1 – heads up/lift vector down
      X = -1 – heads down/lift vector up (normal)

```

PRO

V25E to load entry data.

Flashing
V06N60

G Max
VPRED
GAMMA El

XXX.XX g
XXXXX. ft/s
XXX.XX deg

GMAX is the maximum predicted acceleration for ENTRY at nominal bank angle {L/D ratio = 0.18). VPRED is the predicted inertial velocity at Entry Interface (El) altitude of 400 k ft. GAMMA El is the flight path angle between the inertial velocity vector and the local horizontal at El altitude of 400 k ft.

PRO

Flashing
V16N63

RTOGO
VIO
TFE

XXXX.X nmi
XXXXX. ft/s
XXbXX min/s

RTOGO is the range to go from a preloaded altitude of 297,432 feet to splash.
This is approximately 0.05 g altitude. VIO is the predicted velocity at 297,431 feet.
TFE is the time until 297,431-foot altitude is reached.
RTOGO and VIO may be used for EMS initialization if pad values not available.

PRO

AGCadvances to P62.

P62 - Entry - CM/SM Separation and Preentry Maneuver

Source PDF pages: 90
--- PDF page 90 ---

cM-89

|

P62-ENTRY-CM/SM SEPARATION AND PREENTRY MANEUVER PROGRAM

Purpose:

1. To notify crew when the GNCS is prepared for CM/SM separation.

2. To orient the CM to the correct attitude for atmospheric entry.

Assumptions:

1, The program is entered with adequate freefall time to accomplish CM/SM separation

and complete the maneuver from a worst casestarting attitude.

2. The IMU is satisfactorily aligned for entry.

3. The program is automatically selected by the Entry-Preparation program (P61) or it may be selected manually.

4, The astronaut may monitor N63 (RTOGO, VIO, TFE) by keying in V16 N63 E.

Lda

Sequence of Events:

V37E62E

If entered manually; normally entered automatically from P61.

Average G on. Normally on from P61.

Flashing
VS50N25

Checklist Code

00041

Perform CM/SM separation.

Maneuver to Separation Attitude.

SC Control to SCS.

CM/SM Separation – On.

Maneuver to Horizon Track Attitude.

```

a      PR0
al      Entry DAP Activated
1      Flashing      Impact Latitude      XXX.XX deg
:      V06N61      impact Longitude      XXX.XX deg
|      Roll Attitude      +0000x
|      X = +1 – heads up/lift vector down
|      X= -1 – heads down/lift vector up (normal)
      V25E to load desired data.
      PR0      If angle of attack of CM is within 45 degrees of desired, go to P63.
      V06N22      Desired Gimbal Angles      0GiR)      XX X.XX deg
      IG(P)      XXX.XX deg
      MG(Y)      XXX.XX deg
      Roll angle depends on heads up/down option. Pitch depends on the desired
      angle of attack into the atmosphere. When CM is within 45 degrees of desired
      advance to P63.
      AGCAdvances to P63.

```

nen

P63 - Entry - Initialization

Source PDF pages: 91

--- PDF page 91 ---

- P63-ENTRY-INITIALIZATION PROGRAM

Purpose:

1. To initialize the entry equations.
2. To continue to hold the CM to the correct attitude with respect to the atmosphere for the onset of entry deceleration.
3. To establish entry DSKY displays.
4. To sense 0.05 g and display this event to the crew by selecting the Entry-Post 0.05 g program (P64).

Assumptions:

1. The program is automatically selected by the Entry-CM/SM Separation and Preentry Maneuver program (P62).

Sequence of Events:

P63 entered automatically from P62.

V06N64	Drag Acceleration	XXX.XX g
	Inertial Velocity	XXXXX. ft/s
	Range to Splash	XXXX.X nmi
		(+ is overshoot)

This display may be monitored continuously by keying V16N64E.

OPTIONAL DISPLAYS

V1I6N68E

V16N68	Commanded Bank Angle (Beta)	XXX.XX deg
	Inertial Velocity (V1)	XX XXX. ft/s
	Altitude Rate of Change (HDOT)	XXXXX. ft/s

V1I6N63E

V16N63	Range from EMS Altitude (RTOGO)	XXXX.X nmi
	Inertial Velocity at EMS Altitude	XXXXX.X ft/s
	Time to go Until EMS Altitude	XXbXX min/s

V1I6N74E

V16N74	Commanded Bank Angle (Beta)	XXX.XX deg
	Inertial Velocity	XXXXX. ft/s
	Drag Acceleration	XXX.XXg

Manual track of horizon reduces pitch error needle as pitch attitude approaches the desired angle of attack.

SC Control Switch - CMC/Auto.

Entry DAP now controlling vehicle attitude.

G&N system senses 0.05g drag acceleration.

AGC advanced to P64.

P64 - Entry - Post 0.05G

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P64-ENTRY-POST 0.05 G PROGRAM

Purpose:

1. To start entry guidance at 0.05 g selecting roll attitude, constant drag level, and drag threshold, KA, which are keyed to the 0.05 g point.
2. Select final phase (P67) when 0.2 g occurs if $V < 27,000$ ft/s at 0.05 g.
3. Iterate for upcontrol solution (P65) if $V > 27,000$ ft/s and if altitude rate and drag level conditions are satisfied.
4. Select final phase (P67) if no upcontrol solution exists with $VL > 18,000$ ft/s.
5. To establish the 0.05 g mode in SCS.
6. To continue entry DSKY displays.

Assumptions:

- 1, The program is automatically selected by the Entry-Initialization program (P63).

Sequence of Events:

P64 entered automatically from P63 at 0.05 g.

V06N74,	Commanded Bank Angle (Beta)	XXX.XX deg
	Inertial Velocity (V1)	XXXXX. ft/s
	Drag Acceleration (G)	XXX.XX g

OPTIONAL DISPLAYS

V1I6N64E

V1I6N64	Drag Acceleration (G)	XXX.XXg
	Inertial Velocity (V1)	XXXXxX. ft/s
	Range to Splash (RTOTARG)	XXXX.X nmi

V16N68E

V16N68	Commanded Bank Angle (Beta)	XXX.XX deg
	Inertial Velocity (VI)	XXXXX. ft/s
	Altitude Rate (HDOT)	XXXXX. ft/s

AGC advanced to P65 or P67.

If $VI < 27$ k ft/s at 0.05 g, go to P67 when 0.2 g drag is sensed.

If $VI > 27$ k ft/s, a constant drag trajectory is flown until HDOT becomes more positive than -700 ft/s. A range-to-go check will determine if a controlled skip (P65) phase should be entered. The entry is targeted nominally for a RTOG0 at E1 which will be too small to satisfy P65 requirements and P67 is entered at this point.

P65 - Entry - Upcontrol

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CM-92

P65--ENTRY--UPCONTROL PROGRAM

Purpose:

1. To execute Entry-Upcontrol guidance which steers the CM to a controlled exit (skip out) condition.
2. To establish Entry-Upcontrol displays which are used in conjunction with the EMS to determine for the astronaut if the backup procedures should be implemented.
3. To sense exit (drag acceleration less than Q7 ft/s²) and thereupon to select the Entry-Ballistic Phase program (P66).
4. Where HDOT is negative and the is sufficiently low (V-VL-C18 neg), the program will exit directly to P67 (Final Phase).

Assumptions:

1. This program is automatically selected by the Entry-Post 0.05 g program (P64) when constant drag control has brought range prediction to within 25 nmi of the desired range. It is skipped in earth orbit missions.

Sequence of Events:

P65 entered automatically from P64.

Flashing	Commanded Bank Angle (Beta)	XXX.XX deg
V16N69	Drag Level at Skipout (DL)	XXX.XXg
	Skipout Velocity (VL)	XXXXX. ft/s

PRO Manual response to N69 is not necessary to terminate P65. Selection of P66 or P67 by entry guidance provides automatic termination.

V06N74	Commanded Bank Angle (Beta)	XXX.XX deg
	Inertial Velocity (V1)	XXXXX.ft/s
	Drag Acceleration (G)	XXX.XX g

OPTIONAL DISPLAYS

VING4E

V16N64	Drag Acceleration (G)	XXX.XX g
	Inertial Velocity (V1)	XXXXX. ft/s
	Range-to-Splash (RTOTARG)	XXXXX.X nmi

V1I6N68E

V1I6N68	Commanded Bank Angle (Beta)	XXX.XX deg
	Inertial Velocity (V1)	XXXXX. ft/s
	Altitude Rate (HDOT)	XXXXX. ft/s

AGCadvancesto P66 or P67.

P67 will be entered when HDOT is negative and the velocity is sufficiently low. P66 will be entered when exit is sensed.

P66 - Entry - Ballistic

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P66-ENTRY--BALLISTIC PROGRAM

Purpose:

1. To maintain CM attitude during ballistic (skip out) phase e for atmospheric reentry. ately
2. To sense reentry (drag acceleration builds up to Q7 + 0.5 ft/s² or approximately 0.2 g) and thereupon to select the Entry-Final Phase program (P67).

Assumptions:

4. This program is automatically selected by the Entry-Upcontro! program (P65) when drag acceleration becomes less than Q7 ft/s².

Sequence of Events:

P66 is entered automatically from P65.

V06BN22	Desired Gimbal Angles	OG	XXX.XX deg
	to Orient the Vehicle to	IG	XXX.XX deg
	Correct Angle of Attack	MG	XXX.XX deg

Three-axis control of S/C is regained when acceleration falls below 0.05 g and is relinquished when the drag increases above this value.

OPTIONAL DISPLAYS

VI6N64E

V16N64	Drag Acceleration (G)	XXX.XXg
	Inertial Velocity (V1)	XXXXX. ft/s
	Range to Splash (RTOTARG)	XXXX.X nmi

VI6N68E

V16N63	Commanded Bank Angle (Beta)	XXX.XX deg
	Inertial Velocity (V1)	XXXXX. ft/s
	Altitude Rate (HDOT)	XXXXX. ft/s

V1I6N74E

V16N74	Commanded Bank Angle (Beta)	XXX.XX deg
	Inertial Velocity (V!)	XX XXX. ft/s
	Drag Acceleration (G)	XXX.XXg

AGC advances to P67.

P67is entered at reentry or when approximately 0.2 g is sensed.

P67 - Entry - Final Phase

Source PDF pages: 95

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P67-ENTRY-FINAL PHASE PROGRAM

Purpose:

1. To continue entry guidance after Q7F + 0.5 ft/s² (or approximately 0.2 g) until termination of steering when the CM velocity WRT earth = 1,000 ft/s (altitude is approximately 65,000ft).
2. Tocontinue entry DSKY displays.

Assumptions:

1. The program is automatically selected by:
 - a. P65 when H00T is negative and the is sufficiently low (V-VL-C18 neg).
 - b. P66 when drag acceleration builds up to Q7F + 0.5 ft/s² (or approximately 0.29).
 - c. P64 if no upcontrol solution exists with VL > 18,000 ft/s.

Sequence of Events:

P67 is entered automatically from P64, P65, or P66.

VOG6N66	Commanded Bank Angle (Beta)	XXX.XX deg
	Crossrange Error	XXXX.X nmi (+ south)
	Downrange Error	XXXX.X nmi (+ overshoot)

OPTIONAL DISPLAYS

VI6N64E

V16N64	Drag Acceleration (G)	XXX.XXg
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		Inertial Velocity (VI)	XXXXX. ft/s
		Range to Splash (RTOTARG)	XXXX.X ami
VI6N68E			
	V16N68	Commanded Bank Angle (Beta)	XXX.XX deg
		Inertial Velocity (V1)	XXXXX. ft/s
		Altitude Rate (HDOT)	XX XXX. ft/s
VI6N74E			
	V16N74	Commanded Bank Angle (Beta)	XXX.XX deg
		Inertial Velocity (V1)	XXXXXX. ft/s
		Drag Acceleration (G)	XXX.XXg
	Relative velocity reaches 1,000 ft/s		
	Flashing	Range-to-Splash (RTOTARG)	XXXX.X nmi (+ overshoot)
	V16N67	Present Latitude	XXX.XX deg (+ north)
		Present Longitude	XXX.XX deg (+ east)

SC Control – SCS
Prevent jet firings when Drogue chutes deploy.

PRO

Flashing Select New Program.

V37

Average G off.

P72 - LM Coelliptic Sequence Initiation (CSI)

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CM-95

P72-LM COELLIPTIC SEQUENCE INITIATION (CSI) PROGRAM

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Purpose:

1. To calculate parameters associated with the following concentric flight plan maneuvers for LM execution of the maneuvers under the control of the LGC; the Coelliptic Sequence Initiation (CSI) and the Constant Delta Altitude maneuver (CDH).
2. To calculate these parameters based upon maneuver data approved and keyed into the AGC by the astronaut.
3. To display to the astronaut and the ground dependent variables associated with the concentric flight plan maneuvers for approval by the astronaut/ground.

Assumptions:

1. Ata selected TPI time the line of sight between the LM and the CSM is selected to be a prescribed angle {E} from the horizontal plane defined at the LM position.
2. The time between CSI ignition and CDH ignition must be computed to be greater than 10 minutes for successful completion of the program.
3. The time between CDH ignition and TPI ignition must be computed to be greater than 10 minutes for successful completion of the program.
4. CDH Delta V is selected to minimize the variation of the altitude difference between the orbits.
5. CSI burn is defined such that the impulsive Delta V is in the horizontal plane defined by the active vehicle position at CSI ignition.
6. The pericenter altitude of the orbit following CSI and CDH must be greater than 35,000 feet (lunar orbit) or 85 nmi (earth orbit) for successful completion of this program.
7. The CSI and CDH maneuvers are assumed to be parallel to the plane of the CSM orbit. However, out-of-plane parameters are computed for TIG(CSI) and displayed. In addition, the N81 display is modified to establish an antinode at CSI.
8. If P20 is in operation while this program is operating, the astronaut may hold at any

flashing display and take optics marks, and/or he may allow VHF ranging marks to accumulate.

The ISS need not be on to complete this program unless automatic state vector updating is desired by the Universal Tracking program (P20).

Sequence of Events:

V37E72E

This sequence is identical to the P32 manual sequence when entered at TARGETING. Record maneuver parameters and transmit to LM.

P73 - LM Constant Delta Altitude (CDH)

Source PDF pages: 97

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CM-96

P73--LM CONSTANT DELTA ALTITUDE (CDH) TARGETING PROGRAM

Purpose:

1. To calculate parameters associated with the concentric flight plan maneuvers with the exception of Coelliptic Sequence Initiation (CSI) for LM execution of the maneuvers under control of the LGC. The concentric flight plan maneuvers are the Coelliptic Sequence Initiation (CSI), the Constant Delta Altitude maneuver (CDH), the Transfer Phase Initiation (TPI), and the Transfer Phase Final (TPF) or braking maneuver.
2. To calculate these parameters based upon maneuver data approved and keyed into the AGC by the astronaut.
3. To display to the astronaut and the ground dependent variables associated with the concentric flight plan maneuvers for approval by the astronaut/ground.

Assumptions:

1. This program is based upon previous completion of the Coelliptic Sequence Initiation (CSI) program (P72). Therefore:
 - a. A selected TPI time the line of sight between the LM and the CSM was selected to be a prescribed angle (E) from the horizontal plane defined at the active vehicle position.
 - b. The time between CSI ignition and CDH ignition was computed to be greater than 10 minutes.
 - c. The time between CDH ignition and TPI ignition was computed to be greater than 10 minutes.
 - d. The variation of the altitude difference between the orbits was minimized.
 - e. The CSI burn was defined such that the impulsive Delta V was in the horizontal plane defined by the active vehicle position at CSI ignition.
 - f. The pericenter altitudes of the orbits following CSI and CDH were computed to be greater than 35,000 feet (lunar orbit) or 85 nmi (earth orbit).
 - g. The CSI and CDH maneuvers were assumed to be parallel to the plane of the CSM orbit; however, out-of-plane parameters are computed for TIG(CDH) and displayed. In addition, the N81 display is modified to establish an antinode at CDH.
2. If P20 is in operation while this Program is operating, the astronaut may

- hold at any
flashing display and take optics marks, and/or he may allow VHF rang
ing marks to
accumulate.
3. The ISS need not be on to complete this Program unless automatic state vector updating is desired by the Universal Tracking program (P20).

Sequence of Events:

V37E73E

This sequence is identical to the P33 manual sequence when entered at TARGETING.
Record maneuver parameters and transmit to LM.

P74 - LM Transfer Phase Initiation (TPI) Targeting

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P74—LM TRANSFER PHASE INITIATION (TPI) TARGETING*PROGRAM

Purpose:

1. To calculate the required Delta V and other initial conditions required by the LGC for LM execution of the Transfer Phase Initiation maneuver, given:
Time of ignition (TIG(TPI)) or the elevation angle (E) of the LM/CSM LOS at
a. TIG(TPI).
b. Central angle of transfer (CENTANG) from TIG(TPI) to intercept time TIG(TPF).
2. To calculate TIG(TPI) given E or E given TIG(TPI).
3. To display to the astronaut and the ground certain dependent variables associated with the maneuver for approval by the astronaut/ground.

Assumptions:

1. The program must be done over a tracking station for real-time ground participation in AGC data input and output.
2. {f P20 is in operation while this program is operating, the astronaut may hold at any marks to
flashing display and take optics marks, and/or he may allow VHF ranging
accumulate.
been
3. Once the parameters required for computation of the maneuver have been completely specified, the value of the active vehicle central angle of transfer is computed and stored. This number will be available for display to the astronaut through the use of V06 N52.
The astronaut would call this display to verify that the central angle of transfer of the active vehicle is not within 170 to 190 degrees. If the angle is within this zone, the astronaut should reassess the input targeting parameters based upon Delta V and expected maneuver time.
4. When determining the initial position and velocity of the target at intercept time, either conic or precision integration may be used. The time difference for computation is approximately 10:1 (that is, conic integration is 10 times faster than precision integration).
5. The ISS need not be on to complete this program unless automatic state vector updating is desired by the Universal Tracking program (P20).

Sequence of Events:

V37E74E

at TARGETING.

This sequence is identical to the P34 manual sequence when entered
Record maneuver parameters and transmit to LM.

P75 - LM Transfer Phase (Midcourse) Targeting**Source PDF pages:** 99

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P75—LM TRANSFER PHASE MIDCOURSE (TPM)
TARGETING PROGRAM —

Purpose:

1. To calculate the required Delta V and other initial' conditions required by the LGc for LM execution of the next midcourse correction of the transfer phase of an active LM rendezvous.

Assumptions:

1. IF P20 is in operation while this program is operating, the astronaut may hold at any flashing display and take optics marks, and/or he may allow VHF ranging marks to accumulate.
2. Once the parameters required for computation of the maneuver have been completely specified, the value of the active vehicle central angle of transfer is computed and stored. This number will be available for display to the astronaut through the use of V06 N52.
The astronaut would call this display to verify that the central angle of transfer of the active vehicle is not within 170 to 190 degrees. If the angle is within this zone the astronaut should reassess the input targeting parameters based upon Delta V and expected maneuver time.
3. The time of intercept (T(INT)) was defined by previous completion of the LM Transfer Phase Initiation (TPI) program (P74) and is presently available in AGC storage.
4. There is no requirement for ISS operation during this program unless automatic state vector updating is desired by the Universal Tracking program (P20).

Sequence of Events:

V37E75E

This sequence is identical to the P35 manual sequence when entered at TARGETING.
Record maneuver parameters and transmit to LM.

P76 - LM Target Delta V**Source PDF pages:** 100

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cM-99

P76—TARGET DELTA V PROGRAM

Purpose:

1. To provide a means of notifying the AGC that the LM has changed its orbital parameters by the execution of a thrusting maneuver.
2. To provide to the AGC the Delta V applied to the LM to enable an updating of the LMstate vector.

Assumptions:

1. The CSM crew has the Delta V to be applied by the LM in local vertical axes at a specified TIG. These values are displayed prior to TIG by the Prethrust Targeting program in the LM. No provision is made in these thrusting programs to display the results of the maneuver in a form usable by this routine. If the burn is not nominal

and this Delta V is not as specified or if TIG is not as originally specified, consult backup procedures.

2. In the event of an uplink failure, the astronaut can create a reasonable LM state vector for LM insertion into orbit from the lunar surface by keying in the expected LM thrusting maneuver from the lunar surface while the surface flag is set. This will cause the computer to take the position vector of the landing site and add the inputted Delta V and store the results in the LM state vector. The landing site will not be altered.

3. This program may be selected manually or internally by the MINKEY controller.

Sequence of Events:

If entered automatically by the MINKEY controller, go to Flashing V06N33.

V37E76E

Flashing	Time of ignition of LM thrusting	00XXX h
V06N33	maneuver TIG	000XX min
		0XX.XX s

TIG is loaded with CSM calculated TIG from targeting program
V25E to modify TIG.

PR0

Flashing	Delta V of LM at TIG in	X	−_XXXX.X ft/s
V06N84	Local Vertical Coordinates	Y	−XXXX_X ft/s
		z	XXXX.X ft/s

N84 is loaded with the negative of the CSM targeting solution, modified for out-of-plane velocity (YDOT), IF CSM actually did burn, N84 is loaded with zero.

V25E to modify Delta V.

PR0

1 manual sequence, go to Flashing V37

If MINKEY sequence, the next targeting program in the rendezvous

sequence is initiated. The maneuver sequence is:

Multiple Coelliptic Sequence Initiation (CSI) maneuvers (P32),
OPNHMPBON=

Height Adjustment (HAM) maneuver (P31),

Final Coelliptic Sequence Initiation (CSI) maneuver (P32),

Plane change (PC) maneuver (P36)*,

Constant Delta Altitude (CDH) maneuver (P33),

Transfer Phase Initiation (TP!) maneuver(P34),
 Transfer Phase Midcourse (TPM) number one maneuver (P35),
 Transfer Phase Midcourse (TPM) number two maneuver (P35),
 Final Rendezvous Attitude maneuver and display (P79).
 *If P76 is entered after the PC maneuver and an IMU PC reorientation was
 performed, MINKEY returns to P52 for a realignment of the IMU to its
 original orientation prior to selection of the CDH targeting program.
 Flashing
 v37 Select new program (manual sequence)

P77 - CSM Target Delta V

Source PDF pages: 101

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CM-100

P77-CSM TARGET DELTA V PROGRAM

Purpose:

1. To provide a means of notifying the CMC that CSM has changed (or will change) its orbital parameters by the execution of a thrusting maneuver when Average is not running
2. To provide to the CMC the Delta V applied to the CSM to enable an updating of the CSM state vector.

Assumptions:

1. The crew has the Delta V applied to the CSM in local vertical coordinates at a specified TIG.
2. R03 should be performed after P77 to update CSM mass.
3. The contents of N81 is the same as the previous value at entrance to P77.

Sequence of Events

V37E77E

Flashing VOGN33	TIG at which Delta V maneuver was executed	00XXX h 000XX min 0XX.XX s
--------------------	---	----------------------------------

V25E to Load TIG

PR0

Flashing V06N81	Delta V executed in Local Vertical Coordinates	x Y Zz	XXXX.X ft/s XXXX.X ft/s XXXX.X ft/s
--------------------	---	--------------	---

V25E to load Delta V

PR0

Flashing v37	Select New Program
-----------------	--------------------

P79-FINAL RENDEZVOUS PROGRAM

Purpose:

1. To establish X-axis tracking by P20.
2. To select the rendezvous parameter display (R31) internally to provide range and range rate information prior to the braking phase of rendezvous.

Assumptions:

1. This program may be selected manually or internally by the MINKEY controller.

Sequence of Events:

If entered automatically by MINKEY controller, go to MANEUVER.

V37E79E

Note: If P20 rendezvous options is not running, P20 Option 0 is activated now.

MANEUVER

{f the tracking attitude error between the vehicle X-axis and the LOS to the LM is less than 10 (computed by P20/R61), go to DISPLAY.

Flashing	Desired FDAI angles for	0G(R)	XXX.XX deg
V50N18	automaneuver	1G(P)	XXX.XX deg
			XXX.XX deg

|

MG(Y)

PR0

V06N18 Maneuver in Progress

| When maneuver is complete, go to DISPLAY

Note: P20{R61} will maintain tracking attitude computations. If the attitude error becomes greater than 10 , the astronaut will be alerted by: UPLINK ACTY light on

V58E

Request automaneuver execution. Go to MANEUVER

DISPLAY

Flashing	Range	XXX.XX nmi
V16N54	Range Rate	XXXX_X ft/s
	THETA	XXX.XX deg

PR0

Flashing	
va?	Select New Program

P79 - Rendezvous Final Phase**Source PDF pages:** 101

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CM-100

P77-CSM TARGET DELTA V PROGRAM

Purpose:

1. To provide a means of notifying the CMC that CSM has changed (or will change) its orbital parameters by the execution of a thrusting maneuver when Average is not running
2. To provide to the CMC the Delta V applied to the CSM to enable an updating of the CSM state vector.

Assumptions:

1. The crew has the Delta V applied to the CSM in local vertical coordinates at a specified TIG.
2. R03 should be performed after P77 to update CSM mass.
3. The contents of N81 is the same as the previous value at entrance to P77.

Sequence of Events

V37E77E

Flashing	TIG at which Delta V	00XXX h
V0GN33	maneuver was executed	000XX min
		0XX.XX s

V25E to Load TIG

PR0

Flashing	Delta V executed in	x	XXXX.X ft/s
V06N81	Local Vertical Coordinates	Y	XXXX.X ft/s
		Zz	XXXX.X ft/s

V25E to load Delta V

PR0

Flashing

v37 Select New Program

P79-FINAL RENDEZVOUS PROGRAM

Purpose:

1. To establish X-axis tracking by P20.
2. To select the rendezvous parameter display (R31) internally to provide range and range rate information prior to the braking phase of rendezvous.

Assumptions:

1. This program may be selected manually or internally by the MINKEY controller.

Sequence of Events:

If entered automatically by MINKEY controller, go to MANEUVER.

V37E79E

Note: If P20 rendezvous options is not running, P20 Option 0 is activated now.

MANEUVER

{f the tracking attitude error between the vehicle X-axis and the LOS to the LM is less than 10 (computed by P20/R61), go to DISPLAY.

Flashing	Desired FDAI angles for	0G(R)	XXX.XX deg
V50N18	automaneuver	1G(P)	XXX.XX deg
			XXX.XX deg

|

MG(Y)

PR0

V06N18 Maneuver in Progress

|

When maneuver is complete, go to DISPLAY

Note: P20{R61} will maintain tracking attitude computations. If the attitude error becomes greater than 10 , the astronaut will be alerted by: UPLINK ACTY light on

V58E

Request automaneuver execution. Go to MANEUVER

DISPLAY

Flashing	Range	XXX.XX nmi
V16N54	Range Rate	XXXX_X ft/s
	THETA	XXX.XX deg

PR0

Flashing	
va?	Select New Program

R07 - MINKEY Controller Routine**Source PDF pages:** 102-103

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CM-101

R07-MINKEY CONTROLLER ROUTINE

Purpose

1. To perform automatic sequencing of rendezvous programs
2. To establish Universal Tracking program (P20) Option0, with present values for P20 displays.
3. To perform Target Delta V (P76) after each rendezvous maneuver with appropriately computed P76 displays.

Assumptions:

1. The initialization values for the W matrix must be loaded prior to selection of a rendezvous targeting program

2. This routine is initiated by astronaut selection of a rendezvous targeting program or the Rendezvous Final Phase (P79) program.

Sequence of Events.

The following sequence is presented as a summary of program flow and significant event occurrence for a nominal rendezvous. The MINKEY controller may be activated at any of six reset points: pre-HAM (P31), pre-CSI (P32), pre-PC (P36), pre-COH (P33), pre-TPI (P34), or pre-TPM (P35). This sequence is initiated at the HAM maneuver prior to the final CSI maneuver; however, multiple CSI maneuvering may be sequenced by the MINKEY controller.

P31 (HAM Targeting)

- 1, Start rendezvous navigation (P20, Option 0) with optic tracking assumed; maneuver to track attitude and enable VHF ranging and state vector updating.
Perform HAM targeting computations

oe een

Inhibit rendezvous navigation.
Select a burn program?
Update LM orbital parameters (P76) for LM thrusting maneuver.
Select final coelliptic sequence initiation targeting (P32).

P32 (CSI Targeting)

- 1, Start rendezvous navigation (P20), maneuver to tracking attitude, and enable VHF ranging and state vector updating.
Perform CSI targeting computations.

PeeoeN

Inhibit rendezvous navigation.
Select a burn program*
Update LM orbital parameters (P76) for LM thrusting maneuver.
Selection of a subsequent targeting program is based on the number of apsides (NN) before CDH. For a multiple CSI rendezvous sequence the number of apsides will be greater than 4.

- a. if $NN > 4$, select Coelliptic Sequence Initiation targeting (P32).
- b. If $NN = 4$, select Height Adjust Maneuver targeting (P31).
If $NN < 4$, select Plane Change targeting (P36).

P36 (PC Targeting)

- 1, Start rendezvous navigation (P20), maneuver to tracking attitude, and enable VHF ranging and state vector updating.
2. Perform PC targeting computations.
3. Inhibit rendezvous navigation
4. Plane change realignment option
 - a IF PC Delta V = 0, go to LM Delta V update (P76), Step 7
 - b, -IF PC Delta V $\neq$ 0, select IMU Realignment (P52) program.
 - (1) If X-axis thrusting desired, realign IMU to PC orientation to avoid gimbal lock and go to selection of burn program, Step 5.
 - (2) If Y-axis thrusting desired, IMU realignment is bypassed and RCS burn program (P41) is selected.

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R0? (continued)

5. Select a burn program" (P41 selected if Y axis RCS used).
6. Reorient IMU to original orientation prior to PC realign and maneuver to LM tracking attitude (only if IMU realignment was performed)
7. Update LM orbital parameters (P76) for LM thrusting maneuver
Select Constant Delta Altitude targeting (P33).

P33 (CDH Targeting)

1. Start rendezvous navigation (P20), maneuver to tracking attitude, and enable VHF ranging and state vector updating.
2. Perform CDH targeting computations.
3. Inhibit rendezvous navigation.
4. Select a burn program*.
5. Update orbital parameters (P76) for LM thrusting maneuver.
6. Select Transfer PhaseInitiation targeting (P34)

P34 (TPI Targeting)

1. Start rendezvous navigation (P20), maneuver to tracking attitude, and enable VHF tracking andstate vector updating.
2. Perform TP! targeting computations.
3. Inhibit rendezvous navigation.
4. Select a burn program*.
5. Update LM orbital parameter (P76) for LM thrusting maneuver
6. Select Transfer Phase Midcourse targeting (P35).

P35 (TPM Targeting)

1. Start rendezvous navigation (P20), maneuver to tracking attitude, and enable VHF tracking andstate vector updating.
Perform TPM targeting computations andreinitialize W matrix.

OP ARON

Inhibit rendezvous navigation.

Select a burn program".

Update LM orbital parameters (P76) for LM thrusting maneuver.

Test for completion of midcourse correction (MCC) maneuver.

- a. \f MCC-1 just completed, return to TPM targeting (P35)
for MCC-2 maneuver computations.

- b. 1f MCC-2 just completed, go to final rendezvous (P79).

P79 (Final Rendezvous)

1. Start rendezvous navigation (P20), maneuver to X-axis tracking attitude, and enable VHF tracking and state vector updating.
2. Activate rendezvous parameters display (R31) of range, range rate, and theta.
3. Exit MINKEY autosequencing and manually select new program.

"Automatic selection of a burn program (P40/P41) is based upon the Delta V solution computed in the targeting program

- 1, 'f Delta V < ft/s, the RCS Burn (P41) program is selected.
2. 'f Delta V > ft/s, the SPS Burn (P40) program is selected.

t