SOFTWARE ARCHAEOLOGY

Learning from the landing on the moon!

viadee
IT-Unternehmensberatung

Image: https://commons.wikimedia.org/w/index.php?curid=3984038

"All the News That's Fit to Print"

The New York Times.

LATE CITY EDITION
U. S. Weather Bureau Report (Page 33) forecasts: Cloudy and cool today and tonight. Mostly fair tomorrow. Temp. range: 65—55. Yesterday: 62.4—49.2.

VOL. CVII..No. 36,414. © 1957, by The New York Times Company, Times Square, New York 36, N. Y. NEW YORK, SATURDAY, OCTOBER 5, 1957. 10c beyond 100-mile zone from New York City FIVE CENTS

SOVIET FIRES EARTH SATELLITE INTO SPACE; IT IS CIRCLING THE GLOBE AT 18,000 M. P. H.; SPHERE TRACKED IN 4 CROSSINGS OVER U. S.

HOFFA IS ELECTED TEAMSTERS HEAD; WARNS OF BATTLE

Defeats Two Foes 3 to 1 —Says Union Will Fight 'With Every Ounce'

Text of the Hoffa address is printed on Page 6.

By A. H. RASKIN

Special to The New York Times.

MIAMI BEACH, Oct. 4—The scandal-scarred International Brotherhood of Teamsters elected James R. Hoffa as its president today.

He won by a margin of nearly 3 to 1 over the combined vote of two rivals who campaigned on pledges to clean up the nation's biggest union.

Senate rackets investigators and Hoffa critics in the union rank-and-file immediately opened actions to strip the 44-year-old former warehouseman from Detroit of his election victory.

A jubilant Hoffa exhibited,

Associated Press Wirephoto

IN TOKEN OF VICTORY: Dave Beck, retiring head of the Teamsters Union, raises hand of James R. Hoffa upon his election as union's president. At right is Mrs. Hoffa.

COURSE RECORDED

Navy Picks Up Radio Signals—4 Report Sighting Device

By WALTER SULLIVAN

Special to The New York Times

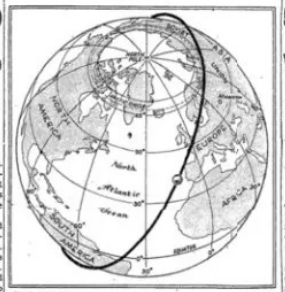
WASHINGTON, Saturday, Oct. 5—The Naval Research Laboratory announced early today that it had recorded four crossings of the Soviet earth satellite over the United States.

It said that one had passed near Washington. Two crossings were farther to the west. The location of the burth was not made available immediately.

It added that tracing would be continued in an attempt to pin down the orbit sufficiently to obtain scientific information of the type sought in the International Geophysical Year.

[Four visual sightigs, one of which was in conjuntion with a radio contact, were reported by early Saturday morning. Two sightings were made at Columbus, Ohio, and one each from Terre Haute, Ind., and Whittier, Calif.]

Press Reports Noted



The New York Times Oct. 5, 1957

The approximate orbit of the Russian earth satellite is shown by black line. The rotation of the earth will bring the United States under the orbit of Soviet-made moon.

Device Is 8 Times Heavier Than One Planned by U.S.

Special to The New York Times.

560 MILES HIGH

Visible With Simple Binoculars, Moscow Statement Says

Text of Tass announcement appears on Page 2.

By WILLIAM J. JORDEN

Special to The New York Times.

MOSCOW, Saturday, Oct. 5—The Soviet Union announced this morning that it success fully launched a man-mad earth satellite into space yester day.

The Russians calculated th satellite's orbit at a maximus of 560 miles above the eart and its speed at 18,000 miles a hour.

The official Soviet new agency Tass said the artificia moon, with a diameter o twenty-two inches and a weigh of 184 pounds, was circling th earth once every hour an thirty-five minutes. This mean more than fifteen times a day

Two radio transmitters, Tas said, are sending signals con tinuously on frequencies o 20.005 and 40.002 megacycles

Source: The New York Times / Wikimedia Commons / NASA

„I believe that this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the Moon and returning him safely to the Earth.“
(John F. Kennedy, 25.05.1961, Special Message to the Congress on Urgent National Needs)

„We choose to go to the Moon...We choose to go to the Moon in this decade and do the other things, not because they are easy, but because they are hard.“
(John F. Kennedy, 12.09.1962, Address at Rice University on the Nation's Space Effort)

Epic 1 (Mercury, 1958-63)

Get an astronaut into an orbit around the earth.

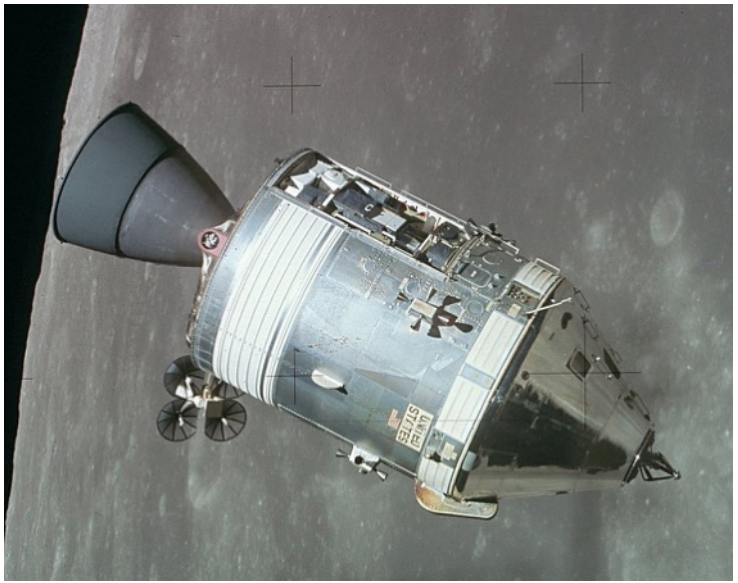
Source: By NASA - https://commons.wikimedia.org/w/index.php?curid=90873932

Epic 2 (Gemini, 1961-66)

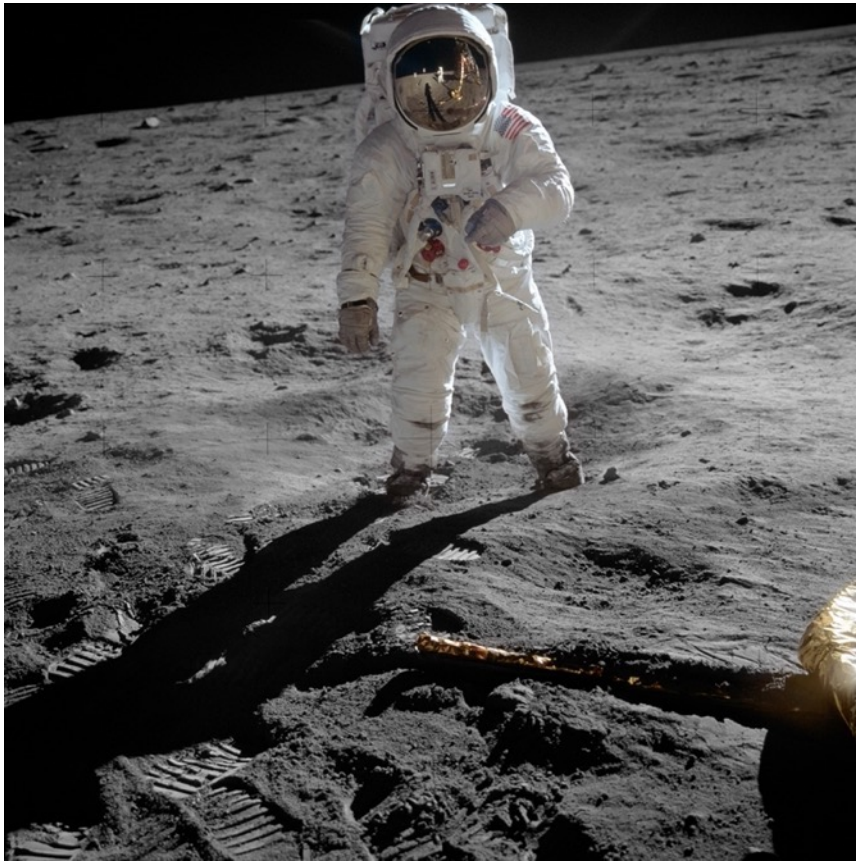
Orbital maneuvers for rendezvous and docking, extra-vehicular activity as preparation for Apollo.

Source: By NASA - Great Images in NASA Description, public domain, https://commons.wikimedia.org/w/index.php?curid=6482593

CSM = Command Service Module
LM = Lunar Module



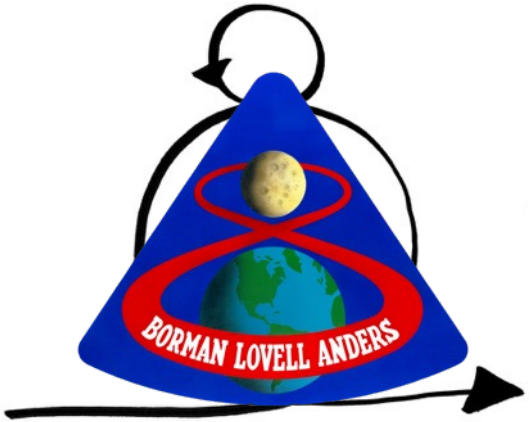
Source: By NASA - http://www.hq.nasa.gov/office/pao/History/alsj/a15/as15-88-11963.jpg, Public Domain, https://commons.wikimedia.org/w/index.php?curid=243484
By Apollo 16 astronauts - NASA photo AS16-116-18580, cropped, Public Domain, https://commons.wikimedia.org/w/index.php?curid=6057549

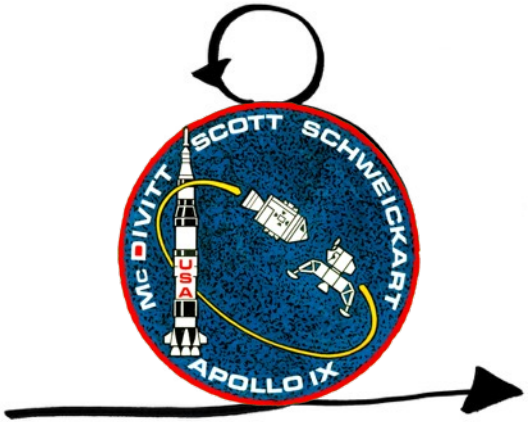


Epic 3 (Apollo, 1961-72)

Moon landing (and safe return)

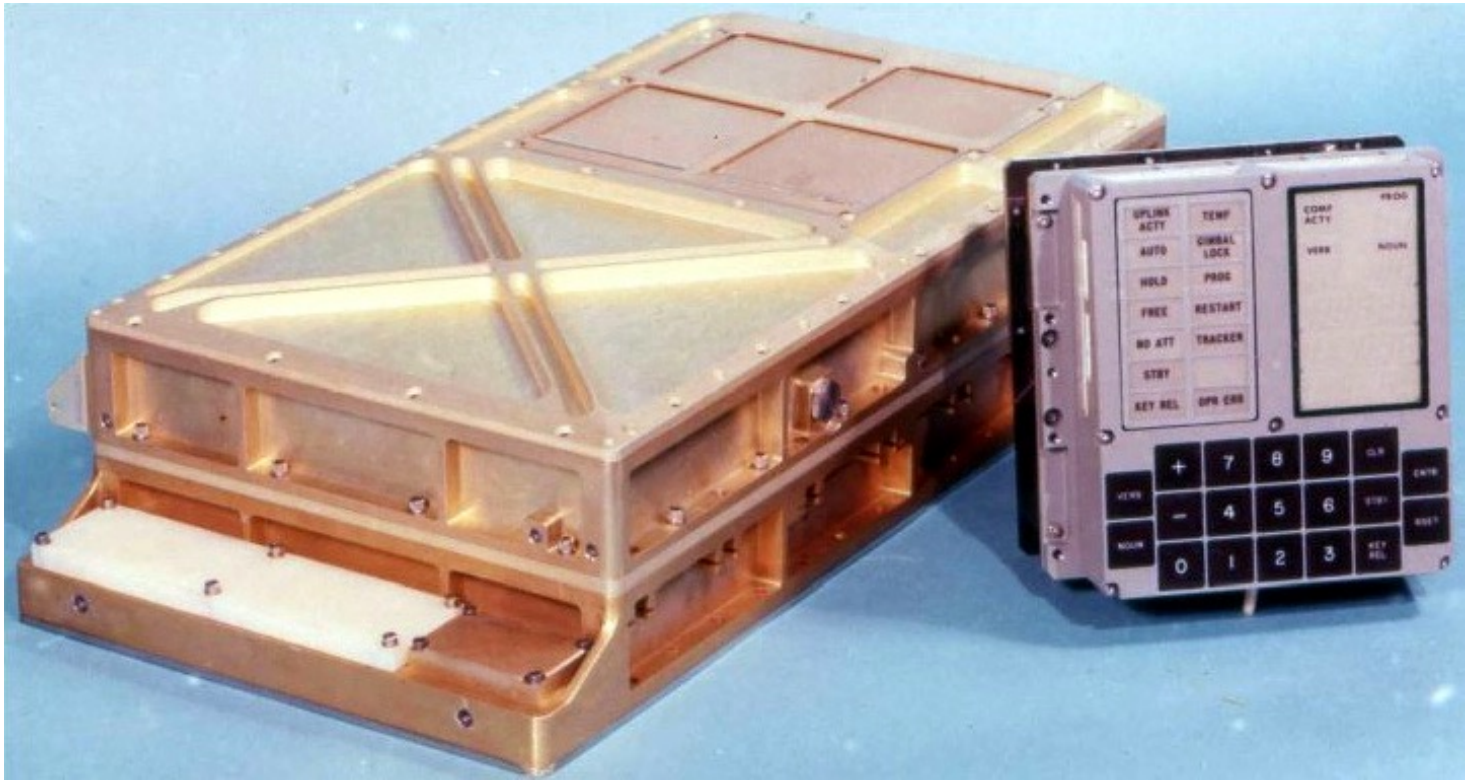
Source: By NASA - http://www.hq.nasa.gov/alsj/a11/AS11-40-5903HR.jpg, http://www.archive.org/details/AS11-40-5903 (TIFF image), NASA Image and Video Library, Public Domain, https://commons.wikimedia.org/w/index.php?curid=3847764





Source: By NASA, Public Domain

AGC = Apollo Guidance Computer



Source: https://commons.wikimedia.org/w/index.php?curid=3984038

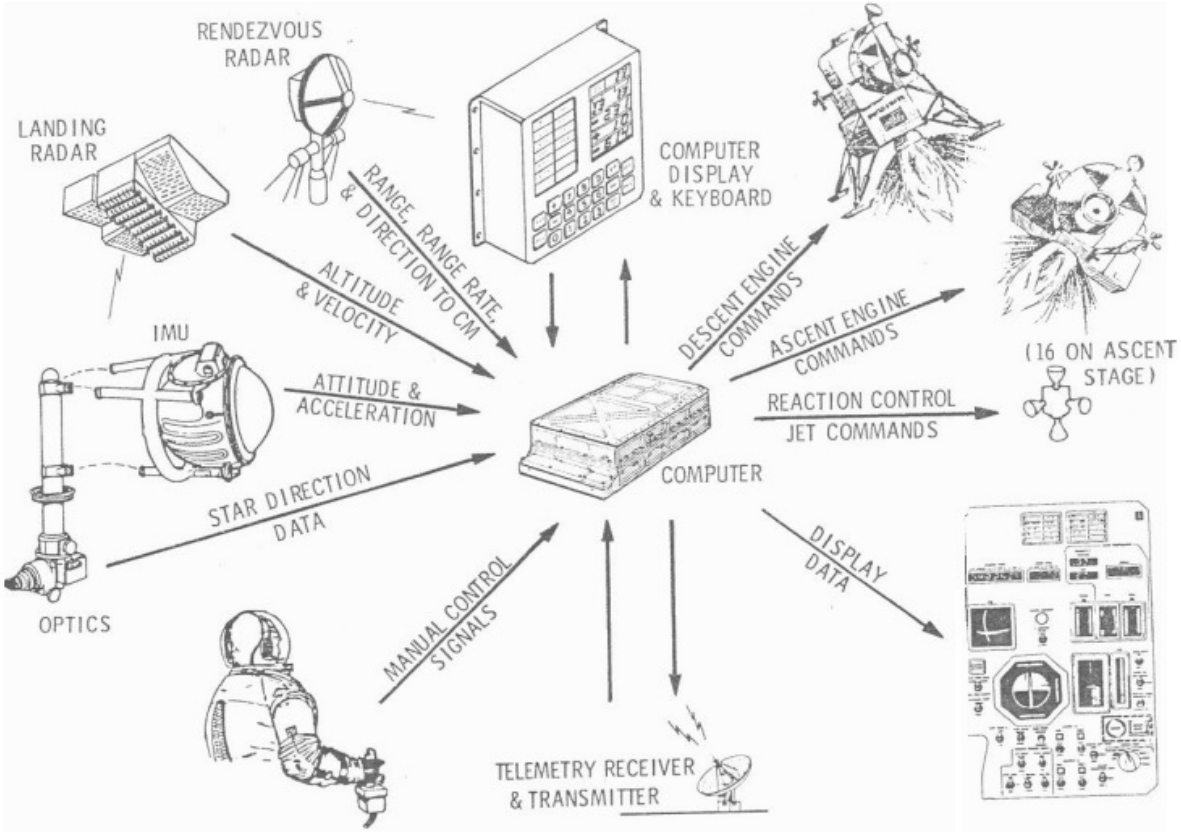


Fig. 3-2 Lunar Module Navigation and

Source: James A. Hand, MIT's Role in Project Apollo (R-700), Volume 1, October 1971

AGC Hardware

55, 33, 15

size in cm (length, width, height)

AGC Hardware

32

weight in kg

AGC Hardware

55

power consumption in watts

AGC Hardware

16

bit architecture
1 sign, 14 data bits, 1 parity bit

AGC Hardware

-16,383 to 16,383

integer range
one‘s complement

AGC Hardware

9

decimal digits numeric precision
realized with a double word (28 bits)
precision of 1 foot (=30,48 cm) at navigation

AGC Hardware

2048

words read/write memory (RAM)
corresponds to 4 KiB

AGC Hardware

36,864

words read-only-memory (ROM)
corresponds to 72 KiB

AGC Hardware

12

length of memory addresses (with 3 bits opcode)
only enough for 4096 words
memory banking (virtual addressing)

AGC Hardware

2

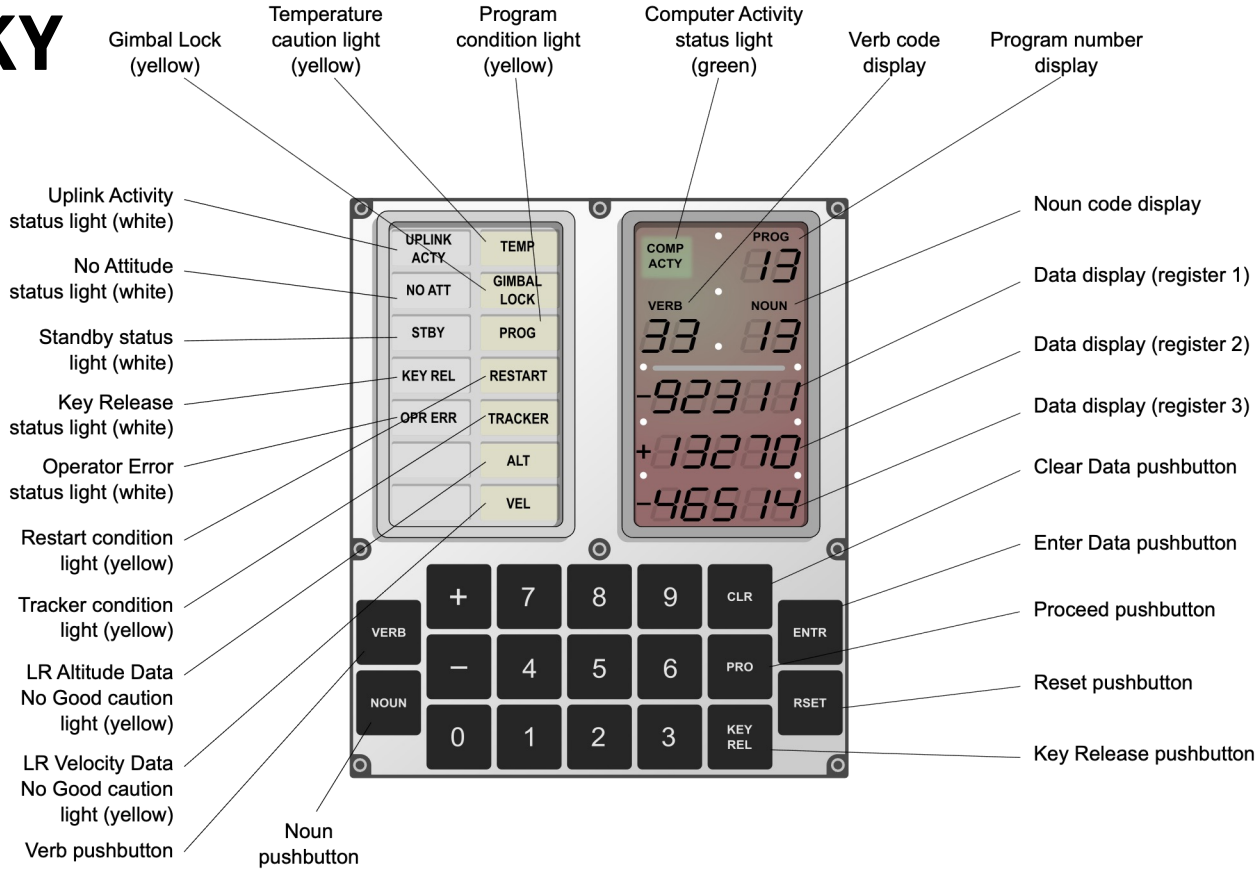
clock rate in MHz

AGC Hardware

51,000 / 1,900

Downlink data rate in bps (bits per second)
to Mission Control („Houston“)

DSKY



Source: By Oona Räisänen & NASA - Self-made in Inkscape; based on the Apollo Operations Handbook (File:DSKYS interface.jpg, by NASA) and a NASA photo from http://www.nasa.gov/centers/dryden/about/Organizations/Technology/Facts/TF-2001-02-DFRC_prt.htm, Public Domain, https://commons.wikimedia.org/w/index.php?curid=8991950

DSKY / AGC Simulator

https://svtsim.com/moonjs/agc.html

Executive = real-time operating system

7

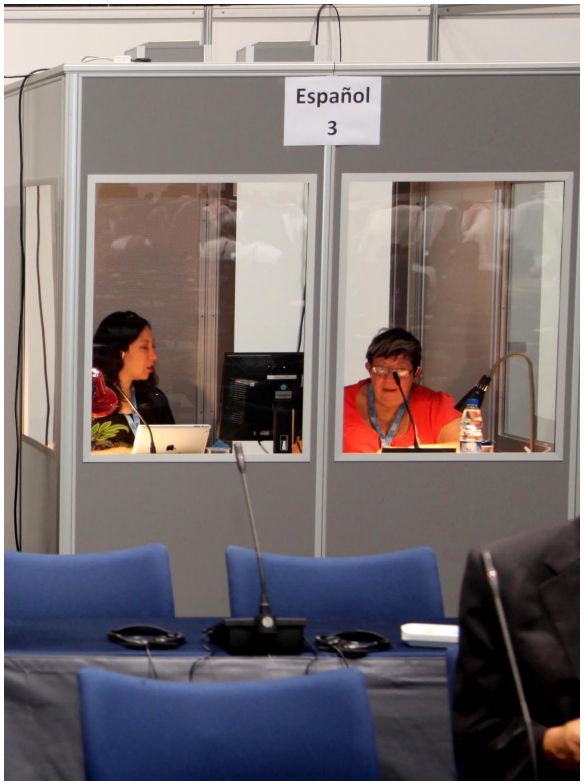
processes ordered by priority
cooperative multi-tasking with NEWJOB

Executive = real-time operating system

11

different interrupts
T3RUPT = TIME3 timer overflow
KEYRUPT1 = keystroke DSKY

Interpreter



Virtual machine

vector & matrix data types
trigonometric & radix functions
index register & stack pointer
simpler addressing without banks
mixed code with Executive assembly

Source: ITU Pictures (CC BY 2.0, cut), https://flickr.com/photos/itupictures/8207252733

https://apolloinrealtime.org/

Alarms

1201

Executive Overflow – NO CORE SETS
→ Exhaustion of core sets, i.e. the set of waiting processes to be scheduled

Alarms

1202

Executive Overflow – NO VAC AREAS
Vector Accumulator (VAC) Area Exhaustion
→ more than 5 Interpreter jobs

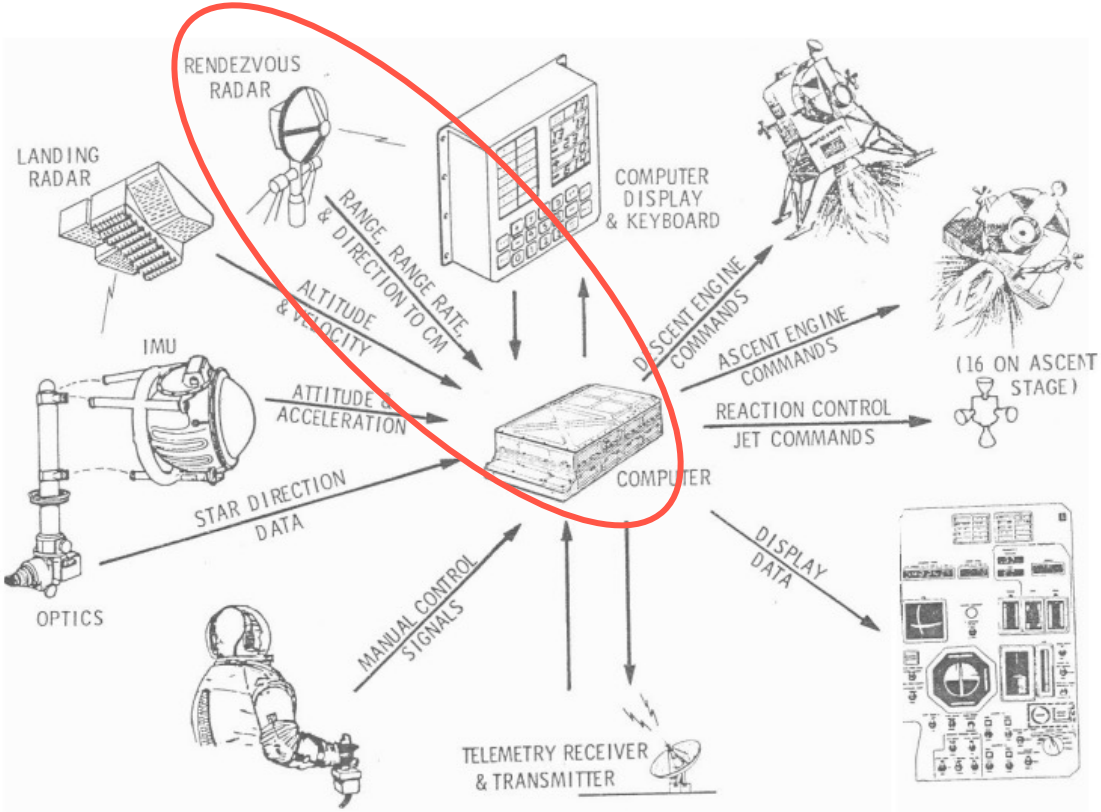


Fig. 3-2 Lunar Module Navigation and

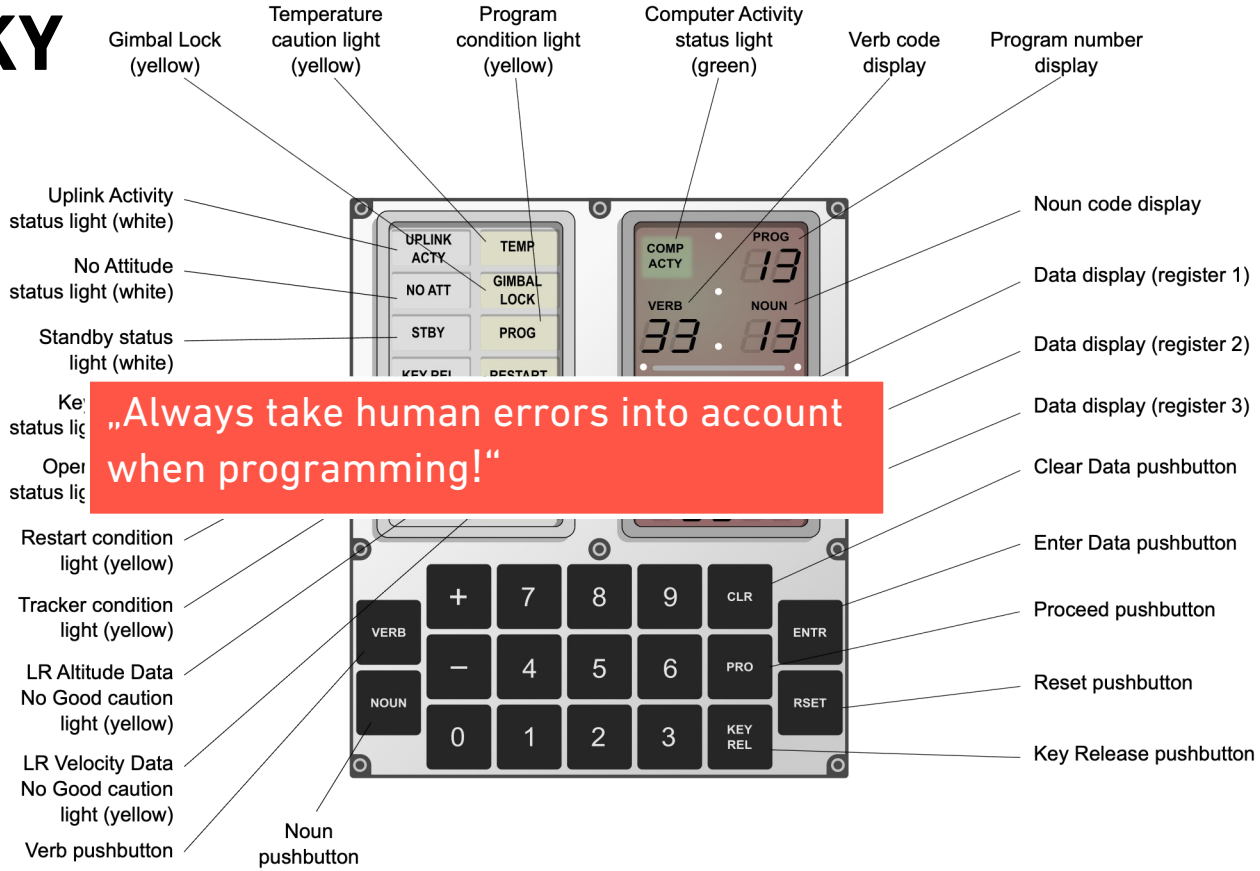
Source: James A. Hand, MIT's Role in Project Apollo (R-700), Volume 1, October 1971

Software Engineering

„The computer (or rather the software in it) was smart enough to recognize that it was being asked to perform more tasks than it should be performing. It then sent out an alarm, which meant to the astronaut, 'I'm overloaded with more tasks than I should be doing at this time and I'm going to keep only the more important tasks'; i.e., the ones needed for landing ...“

(Letter from Margaret H. Hamilton, Director of Apollo Flight Computer Programming MIT Draper Laboratory, Cambridge, Massachusetts, titled "Computer Got Loaded", published in Datamation, March 1, 1971)

DSKY



„Always take human errors into account when programming!“

Source: Von Oona Räisänen & NASA - Self-made in Inkscape; based on the Apollo Operations Handbook (File:DSKYS interface.jpg, by NASA) and a NASA photo from http://www.nasa.gov/centers/dryden/about/Organizations/Technology/Facts/TF-2001-02-DFRC_prt.htm, Public Domain, https://commons.wikimedia.org/w/index.php?curid=8991950

Digital Autopilot

„At MET 102:43:08 (650 feet), after deciding that he could not stop short of the crater, Armstrong flipped the autopilot mode switch from AUTO to ATT HOLD to take manual control of the LM's attitude. He maneuvered to zero pitch to maintain horizontal velocity and skim over the rocky area.“
(http://klabs.org/history/apollo_11_alarms/eyles_2004/eyles_2004.htm)

Source: „Armstrong and Aldrin during Apollo 11 landing rehearsal“, Project Apollo Archive, Public domain, via Wikimedia Commons

Apollo 11's source code is now on GitHub

It's now trivially easy to see the software that helped NASA reach the Moon.

J. Fingas
@jonfingas
July 10, 2016
6:28 PM

In this article: apollo11, apolloguidancecomputer, gear, github, moon, nasa, opensource, personal computing, personalcomputing, science, sourcecode, space, spaceflight

Reuters/NASA/Handout

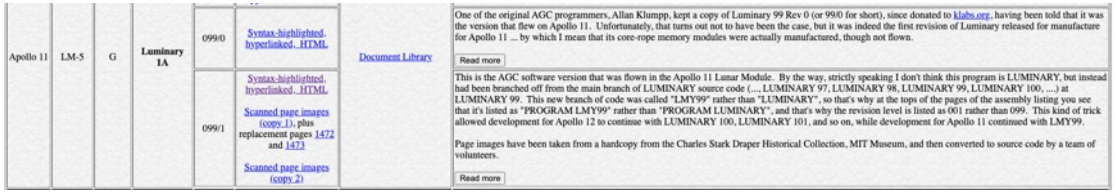
The source code for Apollo 11's guidance computer has been available for a while (Google hosted it several years ago, for instance), but would you know how to find it or search through it? As of this week, it's almost ridiculously

github.com/virtualagc/virtualagc/blob/master/Colossus237/INTERPRETER.agc

```
637  ## Page 1095
638  # SEQUENCE CHANGING AND SUBROUTINE CALLING OPTIONS.
639
640  #          THE FOLLOWING OPERATIONS ARE AVAILABLE FOR SEQUENCING CHANGING, BRANCHING, AND CALLING SUBROUTINES:
641
642  #          1.  GOTO              GO TO.
643  #          2.  CALL              CALL SUBROUTINE SETTING QPRET.
644  #          3.  CGOTO             COMPUTED GO TO.
645  #          4.  CCALL             COMPUTED CALL.
646  #          7.  BPL               BRANCH IF MPAC POSITIVE OR ZERO.
647  #          8.  BZE               BRANCH IF MPAC ZERO.
648  #          9.  BMN               BRANCH IF MPAC NEGATIVE NON-ZERO.
649
650  CCALL           INCR    LOC             # MAINTAIN LOC FOR QPRET COMPUTATION.
651                  INDEX   LOC
652                  CAF     0               # GET BASE ADDRESS OF CADR LIST.
653                  INDEX   ADDRWD
654                  AD      0               # ADD INCREMENT.
655                  TS      FBANK           # SELECT DESIRED CADR.
656                  MASK    LOW10
657                  INDEX   A
658                  CAF     10000
659                  TS      POLISH
660
661  CALL            CA      BANKSET         # FOR ANY OF THE CALL OPTIONS, MAKE UP THE
662                  MASK    BANKMASK        # ADDRESS OF THE NEXT OP-CODE PAIR/STORE
663                  AD      BANKMASK        # CODE AND LEAVE IT IN QPRET.  NOTE THAT
664                  AD      LOC             # BANKMASK = -(2000 - 1).
665                  INDEX   FIXLOC
666                  TS      QPRET
667
668  GOTO            CA      POLISH          # BASIC BRANCHING SEQUENCE.
669   +1             MASK    HIGH4
670                  EXTEND
671                  BZF     GOTOERS         # SEE IF ADDRESS POINTS TO FIXED OR ERAS.
672   +4             CA      BANKSET         # SET EBANK PART OF BBANK. NEXT, SET UP
673                  TS      BBANK           # FBANK. THE COMBINATION IS PICKED UP &
674                  CA      POLISH          # PUT INTO BANKSET AT INTPRET +2.
675                  TS      FBANK
676                  MASK    LOW10
```

Methods / Principles stay

Agile
Planning



Apollo 11	LM-5	G	Luminary 1A	099/0	Syntax-highlighted, hyperlinked, HTML	Document Library
				099/1	Syntax-highlighted, hyperlinked, HTML Scanned page images (copy 1), plus replacement pages 1472 and 1473 Scanned page images (copy 2)	

One of the original AGC programmers, Allan Klumpp, kept a copy of Luminary 99 Rev 0 (or 99/0 for short), since donated to klabs.org, having been told that it was the version that flew on Apollo 11. Unfortunately, that turns out not to have been the case, but it was indeed the first revision of Luminary released for manufacture for Apollo 11 ... by which I mean that its core-rope memory modules were actually manufactured, though not flown.

Read more

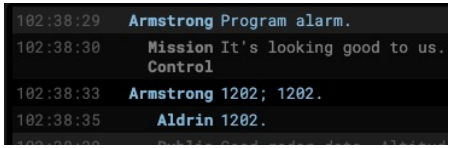
This is the AGC software version that was flown in the Apollo 11 Lunar Module. By the way, strictly speaking I don't think this program is LUMINARY, but instead had been branched off from the main branch of LUMINARY source code (..., LUMINARY 97, LUMINARY 98, LUMINARY 99, LUMINARY 100, ...) at LUMINARY 99. This new branch of code was called "LMY99" rather than "LUMINARY", so that's why at the tops of the pages of the assembly listing you see that it's listed as "PROGRAM LMY99" rather than "PROGRAM LUMINARY", and that's why the revision level is listed as 001 rather than 099. This kind of trick allowed development for Apollo 12 to continue with LUMINARY 100, LUMINARY 101, and so on, while development for Apollo 11 continued with LMY99.

Page images have been taken from a hardcopy from the Charles Stark Draper Historical Collection, MIT Museum, and then converted to source code by a team of volunteers.

Read more

Iterative Design
Simulation

Robust
Fault-tolerant



Vision
Inspiration

Competition
is good for
business

Methods / Principles stay

Abstraction
Virtualization

Thank you for flying through rocket history!

Tobias Voß

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IT-Unternehmensberatung