SPECIAL RELITIVITY

A Different Point of View

APOLLO

NASA Lunar Landing Challenge
An Opportunity to Learn

What was learned from the Apollo project?

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Dedication

To my wife Grace for her patience and support

And to
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My editor and friend

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Introduction

President Kennedy challenged the nation to land men on the moon. Men would be required to travel much farther and faster than possible a few years earlier when Einstein published his paper on Special Relativity in 1905. When Einstein published his paper he imagined a clock in a train moving away and the clock was running slower than his clock. From this thinking about the phenomenon, he developed the theory of Special Relativity.

By 1961, the Apollo Lunar Landing Project became a space race with the Russians who put a man into earth orbit. To win the space race, President Kennedy challenged the nation to land men on the moon within the decade (1961-1969). He put a recently formed government organization NASA (National Aeronautics and Space Administration) in charge of the Project.

NASA realized every detail of the project needed careful planning and documentation. In the first decade of the twenty-first century, NASA published this documentation and made them available on the WWW. The address of all applicable documents is in the Foot Notes.

Navigation was a major issue and a detailed specification was not feasible. There were too many unknowns. Only the general characteristics of the navigation, guidance, and control system could be identified. By 1965 only unmanned, remote controlled spacecraft were sent to the moon (including the soviet Luniks, US Surveyors landers and US Lunar Orbiters), to probe the two bodies navigation and guidance system controlled from earthbound computers and radio-telescopes. But manned trans-lunar journeys and the complex choreography of a manned descend and lunar landing were a complete mystery until the lunar module with lunar orbit rendezvous became the accepted approach. That would require two different guidance systems.

Kennedy's challenge seemed almost impossible. The Apollo Project would be the first time in human history that humans on earth could actually observe a clock traveling away from earth. The Apollo spacecraft carried men (astronauts), a precision navigation system, and a precision clock. The Astronauts could read the time of day from the spacecraft displays of the precision clock's readout. The spacecraft and ground-based instrumentation transmits the clock's readout to earth-based personnel where they could read the spacecraft clock. If necessary, the instrumentation allowed earth personnel to make adjustments to the spacecraft clock.

With this very flexible instrumentation, experiments could have been run to test

Einstein's theory of Special Relativity. Such as, (time dilation) a clock running slower while traveling on Apollo 8 to the moon. None of the navigation, guidance, and control system experts or NASA's navigation experts believed the spacecraft was traveling fast enough to observe any relativistic effects. All attributed the in-flight performance to be a reliability problem, a faulty clock.

Reliability was a serious concern. Computers and most electronic systems would not operate more than a few days without service. NASA put a major effort into the development of techniques to insure astronaut safety. Potential failures of electronics clouded any thinking about the clock's readout. Unknown phenomenon was assumed to be a failure of the electronics.

What was learned about the measurements of position, velocity, and time? What was learned about the performance of the source of time and a clock's readout of the time while traveling at Apollo spacecraft's range and velocities?

Einstein's Approach

Einstein published his paper (1905) on the idea that a train carrying a clock moving relative to an observer's clock at the train station will appear to beat at a different rate than the observer's. From his thinking, Einstein developed his famous mathematical model. The formula determines the magnitude of time dilation as a function of the relative velocity between the clocks.

$$T/T' = \sqrt{1 - (v/c)^2}$$

T is a period of time measured by a stationary clock
T' is the same period of time measured by the clock moving away on a train at velocity "v" with respect to the stationary observer's clock
c is the velocity of light

Julian Schwinger[2], Nobel Laureate for physics in 1965, tells the story of Einstein's work and it's impact on scientific thought in the 20th century. He spends several pages explaining the meaning of non-absolute time and uses time measurements at the Moon and Mars relative to time as measured on the Earth to illustrate. For example, Schwinger states the time on the Moon as observed from Earth is 1.25 seconds behind earth time and time on Mars is about 3.5 minutes behind earth time when Mars is at its nearest point to earth. The spacecraft "Curiosity" landed (Aug 2012) on Mars and the event was observed 14 minutes later on earth. Schwinger acknowledges variations in the time as a function of changes in distance between observer and event when he begins the discussion of time dilation[3].

[2] **Julian Schwinger:** *Einstein's Legacy* (Scientific American Books, Inc. 1986).
[3] **Ibid**, p. 50

Apollo manned lunar landing program

President Kennedy challenged the Nation to land men on the Moon and return them to Earth in the decade (1961-1969). There were many technological challenges for such a mission. Space rocket science was developing rapidly. A manned lunar landing would require ground-based and rocket type technologies to be developed and equipment assembled to meet requirements for manned missions.

Kennedy assigned the task to NASA (National Aeronautics and Space Administration). They recognized a very critical component for a manned lunar landing was the Apollo spacecraft's guidance system. Inertial navigation was the answer and Doctor Charles Draper at the MIT Instrumentation Laboratory was the recognized father of inertial guidance systems.

NASA chose to follow the very successful Navy Program plan that developed the Polaris Fleet Ballistic Missile and awarded the first major contract to MIT Instrumentation Laboratory. The Navy's MIT contract for Polaris missile guidance systems started in 1956. Polaris missiles required an inertial guidance system. They were developed and put into production by an industrial contractor under the direction of Dr. Draper at MIT's department of Aeronautics and Astronautics Instrumentation Laboratory. By 1961 the Polaris program was in the production phase of the second-generation (Mark II) guidance system. Raytheon and MIT's personnel were working together very successfully during the design and production of the Polaris Mark II guidance system's computer, and Raytheon became the industrial support contractor for the Apollo guidance system's computer[4].

Included in NASA's early decisions was the requirement to use the English system of measurement and to make the spacecraft's inertial guidance system function independent of ground control. To accomplish this independence, the guidance system would have optical sighting equipment to measure and to compute the spacecraft's state vector parameters (position and velocity). The "time of day" for

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[4] **Eldon C Hall**, *Journey to the Moon* American Institute of Aeronautics and Astronautics, Inc. Reston, VA. 1996 p.43 The Polaris Mark I guidance system's design was complete and flew late in 1959. Mark 1 systems were operational for many years. By 1961 the Polaris Mark II guidance system was in production and had flown test flights. The Polaris computer introduced hardware technologies (integrated circuits, welded cordwood fabrication, and wire-wrap interconnections p.17 p.43 p.27) that were applicable in the Apollo guidance computer.

the state vector computation was the time an astronaut reads from the DSKY (the display and keyboard component of the Apollo Guidance Computer).

The source of time in the guidance system's computer is a 2.0480 megacycle quartz-crystal controlled oscillator[5], which drove a countdown chain in the logic of the computer. The countdown chain provides timing for all spacecraft systems and the guidance system's time of day (clock). This design was a NASA requirement for the oscillator's beat-rate and the time of day clock. The countdown chain could not be modified by software. Software can read the contents of the count down chain periodically and displays that time on the guidance computer's display panel (DSKY) in hours, minutes, and seconds quantized to 1/100th of a second.

The Command Module (CM) guidance system's software and the Lunar Module (LM) guidance system's software would compute the state vector parameters (position and velocity at the precise time defined in each computer's count down chain). The CM has the guidance system's (GNCS's) computer programmed to guide the CM from Earth to Lunar-orbit and return to an Earth-landing. The LM has the guidance system's (PGNCS's) computer programmed to guide the LM to a Lunar landing and return to Lunar-orbit where it would rendezvous with the CM. In both systems the software memory registers (built in the mission Core-Rope memory), the DSKY display, and the mission software (the guidance and navigation mission subroutines) were designed to store, display and process the state vector (x, y, z, x-dot, y-dot, z-dot and time). That state vector was the soul of the Apollo system. All the mission software and hardware were designed around this mathematical entity. These requirements made it possible for a mission to return to earth without astronaut or ground control.

The following quotation is from NASA documents where Dr. Robert C. Duncan outlines the fundamental requirements for the on-board navigation, guidance, and control system[6].

"Dr. Gilruth calls the participants to order with a mild scolding. We're already five minutes over the announced time to reconvene!

…

The purpose of the guidance system is to control the position and velocity of the vehicle. The navigation process involves the determination and indication of position and velocity, and the guidance process involves controlling these

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[5] **Ibid,** p. 122 Quart-crystal controlled oscillators demonstrated reliable operation in the Polaris computer.

[6] **http://Spaceref.com/missions and programs/nasa/apollo/** Apollo Navigation Guidance and Control. 1966.

quantities in a closed-loop fashion. Figure 1 shows a generalized functional diagram of the guidance and control system. In order to minimize guidance errors the system must reduce the effect of interfering quantities, and it must respond quickly to command signals. An inertial guidance system is fundamentally mechanized as a specific force measuring system using single axis accelerometers, which operate in coordinates that are determined by gyros.

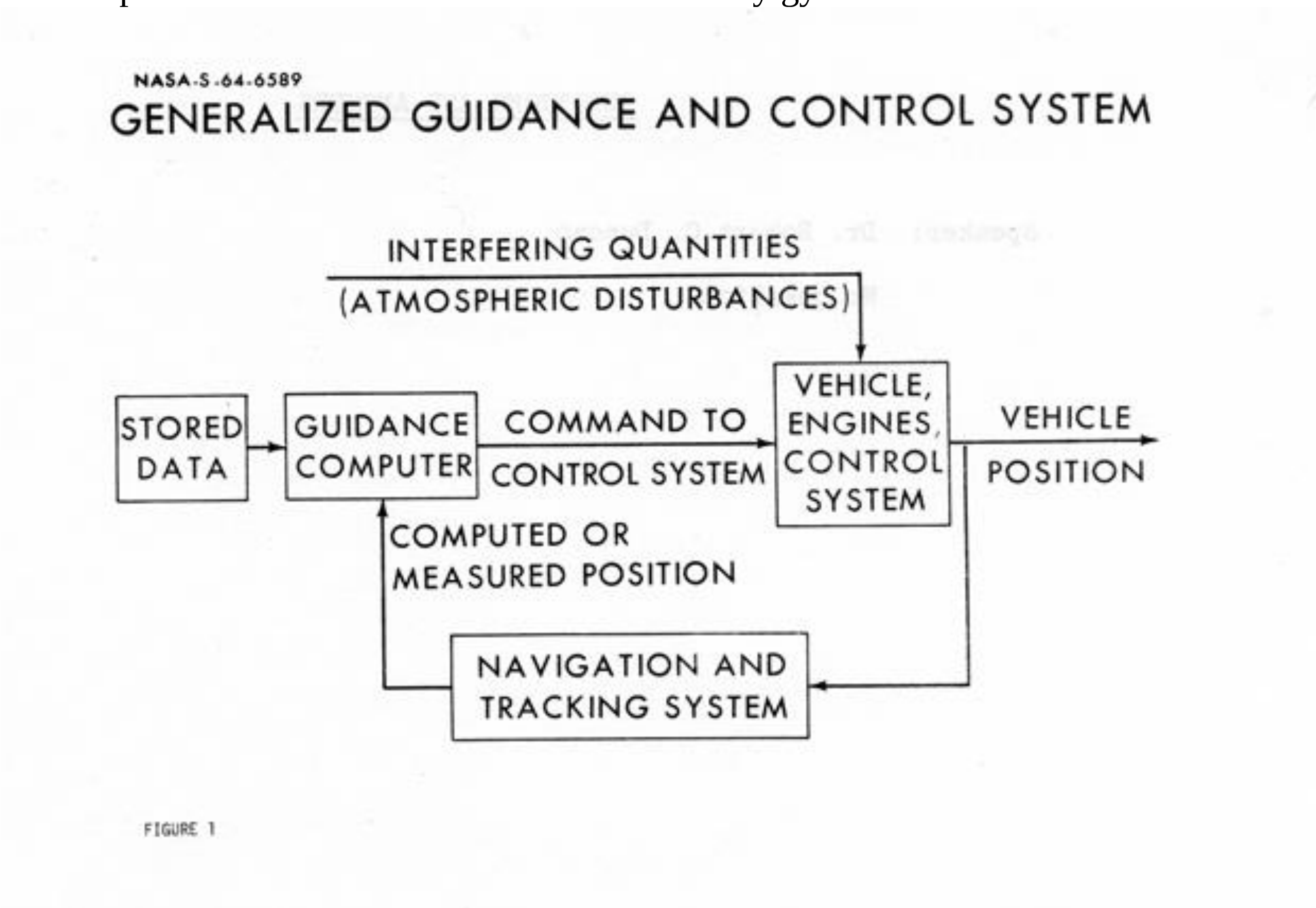

Figure 01

The guidance system operates as a force-vector control system, i.e., the system must change the direction and magnitude of controllable forces (lift, drag, and thrust) in such a way that the vehicle reaches its desired point in space and time. It is usual in the theory of dynamics of rigid bodies in three dimensions to separate the motion of the center of mass from the motion of the body around the center of mass. Guidance is the process of moving the center of mass of the vehicle along some desired path. Stability and control are associated with motions about the center of mass.

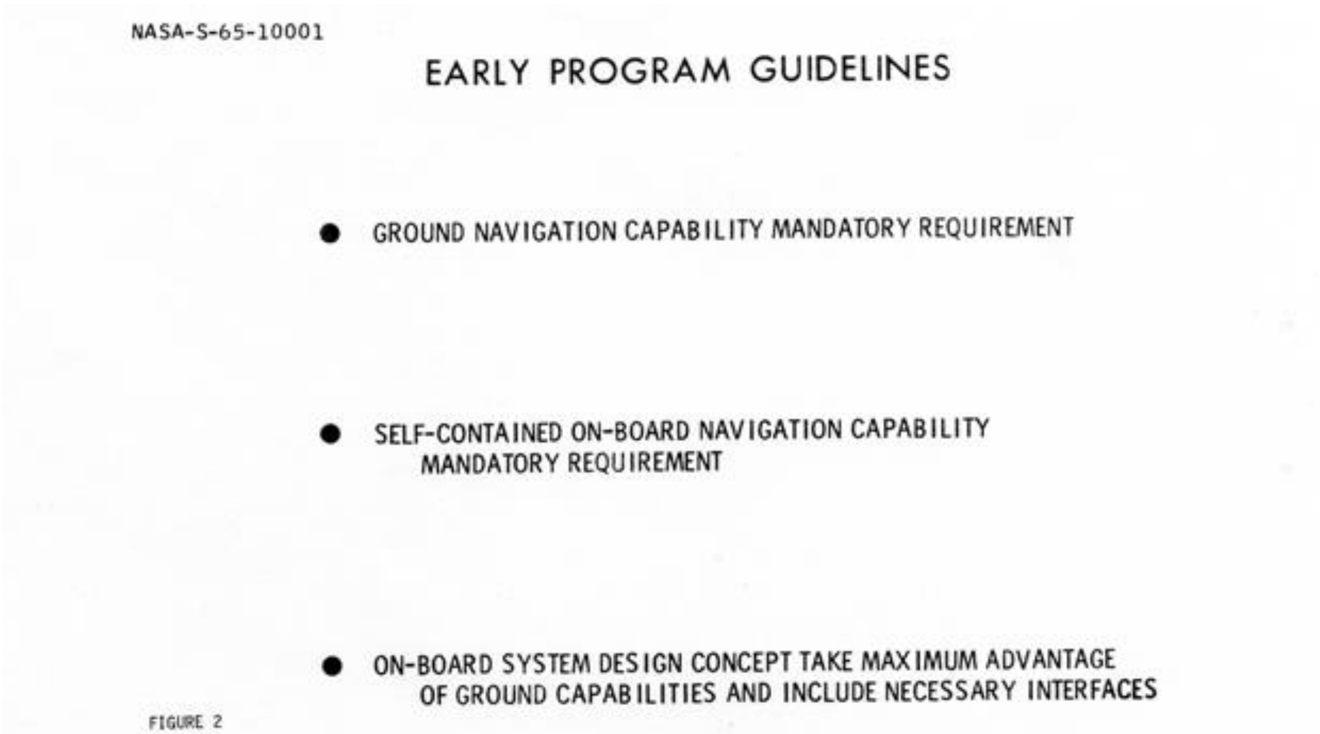

Figure 02

The guidance and control systems for all manned spacecraft have involved a mix of spacecraft systems and ground systems. Figure 2 shows the guidelines used in the Apollo program for this mix of spacecraft and ground systems: It is mandatory that there be a ground navigation capability provided in earth orbit, cislunar space, lunar orbit, during the lunar landing phases, and during the lunar rendezvous phases.

It is mandatory that the spacecraft contain onboard a completely self-contained navigation, guidance, and control capability to be used in the event that the data link with the ground is lost.

The onboard system is designed in such a way to take maximum advantage of the ground system and to include all necessary interfaces.

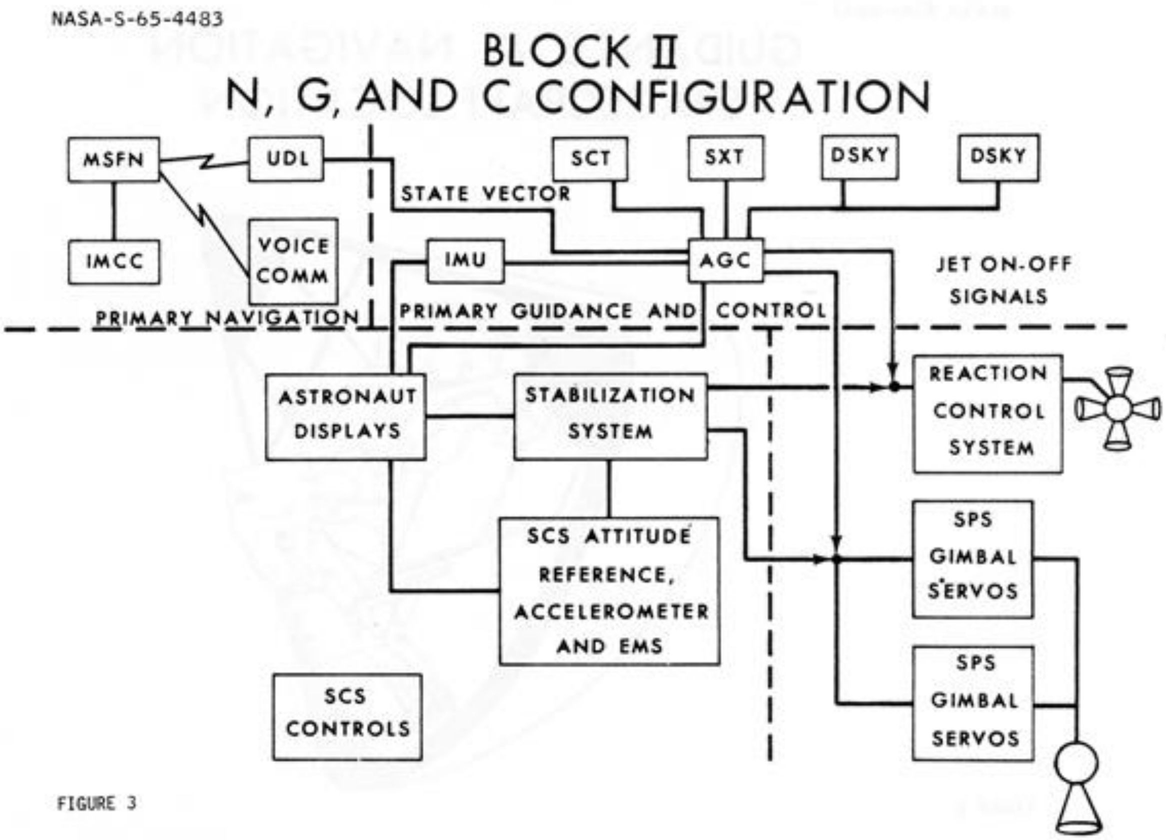

Figure 03

Figure 3 shows the navigation, guidance, and control system which evolved for the command module. The LEM system is very similar and will be discussed later. The primary navigation system in cislunar space is the ground system. This consists of the manned space flight network (MSFN) comprised of a number of tracking stations around the world operating in conjunction with the Houston Mission Control Center (MCC). This system is connected to the onboard system by way of the updata link and voice communications. The updata link provides the navigation state vector to the Apollo guidance computer (AGC). The primary guidance and control system consists of the AGC, the inertial measurement unit (IMU), the scanning telescope (SCT), sextant (SXT), and the display and keyboard assembly (DSKY).

The primary guidance and control system operates the reaction control system (RCS) which is used primarily for attitude control in space and during reentry. The AGC also activates the gimbal servos to drive the service propulsion (SPS) engines. In the event the primary control system has a failure, the backup system (labeled in Figure 3 the Stabilization System) can also drive the reaction control system and the SPS gimbals. The SCS (stabilization and control system) provides an attitude reference and also has an accelerometer to measure AV. The entry monitor system (EMS) is a simplified backup guidance system to be used during the entry phase of the mission in the event of failure of the primary system. An integral part of both the primary system and the backup stabilization system is the astronaut. He obtains information from the computer by the DSKY and from the display panel. He communicates with the computer through the DSKY and is able to control the system through the use of the engine throttle and attitude hand controller".

As the Apollo Program developed, NASA set up Mission Control to function as primary for spacecraft navigation and to manage missions. For navigation, Mission Control computed the spacecraft's state vector parameters (position, velocity, and time) from the Manned Space Flight Network Tracking System (MSFN).

The following quotation is from the previous NASA document. Here Dr. Duncan outlines the function of the MSFN system[7].

"A schematic representation of the operation of the manned space flight network tracking system (MSFN) is shown in Figure 13.

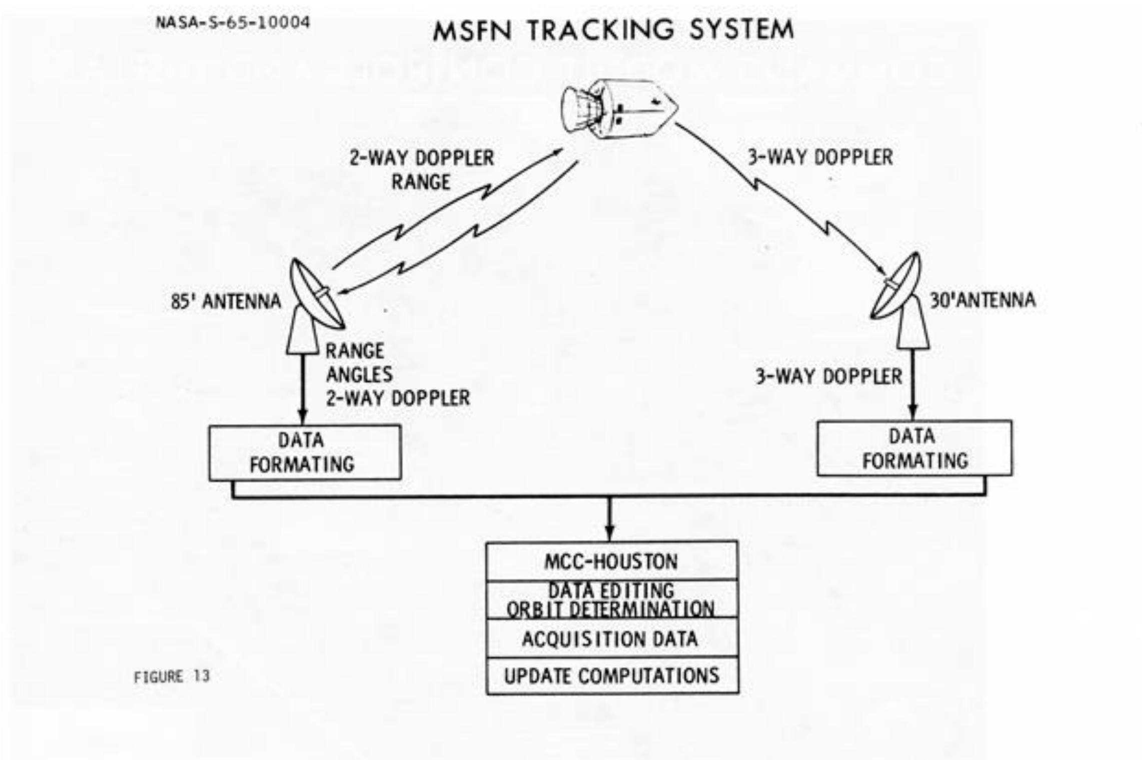

Figure 13

[7] **http://Spaceref.com/missions and programs/nasa/apollo/** Apollo Navigation Guidance and Control. 1966.

The vehicle is illuminated by an 85-foot antenna, which provides range, angles, and velocity.

This information is transmitted to the Mission Control Center in Houston from which navigation information is determined. The vehicle can also be tracked by 30-foot antennae which use three-way Doppler information to provide position and velocity data. Distance is determined by modulating the carrier with random digits (0 and l). The signal is received by transponders in the CSM or the LEM and retransmitted. The measurement of transit time of the signal is a measure of the distance of the spacecraft. Velocity is determined by measuring the Doppler shift in the signal returned by the spacecraft."

Later in the Apollo program's development, Mission Control decided to use Ground Elapsed Time ("GET") for timing in-flight events. So, used GET in simulators to train astronauts, test software, verify hardware, and evaluate the mission's flight procedures. Contractors like those developing guidance system's software, developed simulators using various methods for timing.

Apollo 8

The first lunar mission (Apollo 8 Dec 1968) tested the facilities, instrumentation, and procedures in preparation for a landing in 1969. Apollo 8 is the first time in human history that a spacecraft carrying men with a precision navigation system flew this far and fast. These men, astronauts, in the spacecraft could observe lunar events 250,000 nautical miles from earth.

In preparation for the Apollo 8 mission, Mission Control detected the Command Module Clock (CMC) was not synchronized with Mission Control's Clock. The CMC oscillator's beat-rate was 0.953-milliseconds/hr slower than the beat-rate of Mission Control's clock both before and after launch[8]. A requirement to synchronize clocks had not been recognized during the computer's design. If it had, the designers would not have known how to synchronize the clocks either.

This clock synchronization problem was not observed during simulations and astronaut training operations where Mission Control's clock and guidance system's clock had to be synchronized within a few 1/100th of a second Since nobody knew what made the beat-rate slower in-flight, the Houston guidance system support team told Mission Control that the clock was not precision and would need to be

[8] **APOLLO 8 Mission Report MSC-PA-R-69-1** p.6-47. Mission Control can measure the beat-rate much more accurately than is possible by DSKY readouts.

updated in-flight. Julian Schwinger demonstrates the requirement for this update in his journey to Vega thought experiment[9].

This quotation[10] from the NASA document Day 3: The Maroon Team records the first DSKY time update.

"058:9:24 Anders: Okay. We'll, I'll mention it to them when they wake up.
[Very long comm break.]
Public Affairs Officer - "This is Apollo Control at 58 hours, 12 minutes. We have just been in touch with the spacecraft and received a status report from Bill Anders on the condition of the spacecraft windows at this time. We'll ... stand by briefly, for any further communications with the spacecraft."
Public Affairs Officer - "And it appears that we'll have no further communication at this time with Bill Anders, aboard the spacecraft. We're continuing to monitor the velocity and altitude as it approaches the Moon. At the present time, our velocity reading is 4,030 feet per second [1,228 m/s] and we're at an altitude above the Moon of 27,575 nautical miles [51,069 km]. Our predictions in Mission Control Center are that the velocity will, of course, continue to accelerate as we approach the Moon rather slowly for the next 7 hours or so and we anticipate that by about 65 hours, the velocity will be somewhere around 4,350 feet per second [1,326 m/s]. That would be an increase of about 300 feet per second over what we're showing now. The dramatic increase in the velocity will come between 65 hours and 69 hours, at the point of Lunar Orbit Insertion, when the velocity will just about double, going from 4,350 feet per second up to about 8,420 feet per second [2,566 m/s]. At 58 hours, 18 minutes into the flight; this is Apollo Control, Houston."
058:30:34 Mattingly: Apollo 8, Houston.
058:30:40 Anders: Go ahead, Houston.
058:30:42 Mattingly: Okay. Apollo 8, we'd like to update your CMC clock. This is not to correct errors which we have now but just to make up for some effects that

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[9] **Julian Schwinger:** *Einstein's Legacy* (Scientific American Books, Inc. 1986). p.116. Schwinger discusses the "Twin Paradox" problem in Special Relativity and places a strobe light on earth and one on the spacecraft that is traveling to Vega and back. He states that the strobe on the spacecraft flashes slower than the earth-based strobe on the outward-bound journey to Vega.

[10] **http://history.nasa.gov/ap08fj/.** At GET 058:38:14 Mission Control made the first DSKY time update. This first update must have been the result of the oscillator's beat-rate being slow and a much larger contribution from the "clock" running slower just as in Einstein's train experiment. If so, the clock was set forward (adding time) to read out the correct "GET" on the astronaut's DSKY.

we're going to have in lunar orbit. And what we'd like to have you do is go to P00 and Accept and let us update the clock time.

058:31:04 Anders: Stand by. [Long pause.]

058:31:23 Anders: Okay. You got P00 and Accept.

058:31:25 Mattingly: Roger. Thank you.

[Long comm break.]

[By placing the computer in program 00 and throwing the Up Telemetry switch to the Accept position, Mission Control are given direct access to the computer. In this case, the registers that hold the current value for time are being updated.]

[Readers should note that the CMC clock is not the same as the mission clock or timer. They are very separate things. One is concerned with time with respect to the motions of the planets while the other is purely concerned with how the crew and Mission Control schedule their work. Indeed, on some missions, the mission timer would be altered to compensate for a late launch, allowing the crew to return to their original schedule.]

Public Affairs Officer - "This is Apollo Control at 58 hours, 37 minutes. At the present time, our spacecraft velocity is 4,037 feet per second [1,230 m/s] and we are at an altitude now of 26,764 nautical miles [49,567 km] above the Moon. We had one rather brief conversation with Bill Anders in the past 15 minutes or so and have not heard from the spacecraft since. During that conversation, we passed up to the spacecraft an update to the computer driven clock aboard the spacecraft and that pretty much summarized the content of that communication. We'll ... pick up live with conversations that are going on at the present time."

058:38:07 Mattingly: Apollo 8, Houston.

058:38:13 Anders: Go ahead, Houston.

058:38:14 Mattingly: Okay. We're completed with the clock update, and the computer is yours."

A detailed explanation is necessary to clarify this result. The guidance system was designed to determine the spacecraft's state vector parameters (position and velocity) as computed from astronaut's optical star sighting data. The precise "time of day" is red from the computer's clock in the countdown chain by the astronaut's command to "Mark" the time of the measurement. The accuracy of this procedure was considered satisfactory for spacecraft navigation. But, the spacecraft's guidance system could not determine the time for the next important event LOS (Lose of radio signals when the spacecraft passes into the shadow of the moon) using optical star sighting data.

Mission Control had to compute the spacecraft's predicted state vector parameters (position and velocity) from MSFN measurements made just before the event. The spacecraft's range (position) is measured from the time required for the radar signal's reflection from the spacecraft to travel the 225,000 nautical miles moon to earth. The spacecraft's velocity is measured by MSFN Doppler data (~4,000 feet/second). For the "time of day" in the state vector, Mission Control must use the DSKY readout sent by telemetry or must use the control room's clock.

At GET 058:38:14, Mission Control set the DSKY's display of time forward (added time) to compensate for the slow beat-rate of the computer's oscillator. Therefore, the predicted time for LOS was a test of Mission Control's computations using the MSFN range measuring radar. Mission Control's personnel, as very few radar range operators on earth, had no experience with radars operating at spacecraft velocities and lunar ranges and most likely did not compensate for the 1.25 seconds transmission delay when computing the spacecraft's state vector (for position and velocity at Mission Control's precise time). They predicted LOS to occur at 068:58:04 GET using MSFN data and as predicted the astronauts observed the time for LOS as accurately as possible on the DSKY, 068:58:04 -0, +1.

This quotation[11] from the NASA document Day 4: Lunar Encounter records the LOS event.

"[Apollo 8 has just disappeared behind the Moon's western limb and will be out of radio contact with Earth for a period of time that depends on what the crew do in the next few minutes. If they do nothing, the Moon's gravity will sling them around and send them back towards Earth. They would then re-emerge from behind the eastern limb 22½ minutes later, having aborted the mission. What they actually intend to do is fire their SPS (Service Propulsion System) engine for a little over four minutes against their direction of travel, slowing them down enough to be captured by the lunar gravitational field. If this burn works as expected, then the trajectory experts and their computers have calculated that Apollo 8 will reappear 32 minutes, 37 seconds after it disappears. Any deviation from the planned burn will affect this duration, making it a good initial test of the burn's fidelity and their trajectory.]

[In the minds of many, this temporary interruption of Apollo 8's communication link by the massive bulk of another world is a most profound step in human exploration, at least since the flight of Yuri Gagarin. Arguably, it is of equal historical importance and almost certainly represents the point where America was deemed to have essentially won the race to the Moon. Though Apollo 11 would come to be the remembered mission, Apollo 8, made the political point. This is borne out by the fact that the Soviets were pushing to achieve a similar manned circumlunar flight in the months leading up to Apollo 8 with which they would have undoubtedly claimed the kudos of reaching the Moon first.]

Public Affairs Officer - "This is Apollo Control, Houston. They're traveling over

[11] **http://history.nasa.gov/ap08fj/ The time 068:58:04** This quotation records the time of Lovell's DSKY read-out of LOS.

the back side of the Moon now. Velocity readings here; 7,777 feet per second [2,370 m/s]. At the present, time we show an altitude above the Moon of 293 nautical miles [543 km]. So at 69 hours, 1 minute, this is Apollo Control, Houston."

[While out of view and radio range of the Earth, telemetry on the spacecraft's most vital systems is being collected and stored on the DSE (Data Storage Equipment). The crew's conversations are also recorded on this tape, whose contents will be replayed to Earth once they come around for a near-side pass.]

068:58:02 Lovell (onboard): 58:04.

068:58:06 Borman (onboard): Geeze.

[Just as Jim Lovell reminded his commander, Frank Borman, of the exact time they were calculated to lose the S-band radio signal from Earth, it was lost, a precision by the Earthbound computers of some wonder to Frank.]

068:58:10 Anders (onboard): S-Band Volume, down.

068:58:12 Borman (onboard): That was great, wasn't it? I wonder if they've turned it off.

068:58:19 Anders (onboard): [Laughing.] Chris probably said, "No matter what happens, turn it off."

[Chris Kraft is very much the boss in Houston. At the time of Apollo 8, he is the Director of Flight Operations and the man the Flight Directors report to. The joke that Bill Anders injects is to suggest that Kraft would have ordered the people at the transmitting station to turn off the radio signal at the right time so as not to worry the crew if the predictions had not been so accurate.]"

There were guidance system design teams in Houston and Cambridge monitoring the operation of the guidance system and provide help to Mission Control when necessary. The Houston team did not understand that the CMC was a precision clock and did not report the in-flight operation of Apollo 8 to any qualified hardware or software designers in the Cambridge design team[12]. The fact that the two clocks were not calibrated to beat at the same rate, the CMC and the Mission Control's clock would not stay synchronized in flight. The in-flight performance was never reported to the MIT (Cambridge) design team. Everybody believed the clock was faulty. During the mission simulations and astronaut training operations, the performance of the CMC was satisfactory.

[12] The fact that the two clocks were not calibrated to beat synchronously was never reported to the MIT (Cambridge) design team. The Houston guidance system design team reported to NASA that the computer's clock was not a precision time keeping device.

The Mission Report[13] states that the CMC was updated several times to maintain synchronization with GET. The only recorded clock updates were at GET 058:30:42 (it added time) when the spacecraft had traveled approximately 225,000 knots (one knot is 6076.11 feet) from the earth and at GET 121:13:17 (it subtracted time) when the spacecraft was retuning to earth and was approximately 118,000 knots above the earth. The several times statement could include time changes that were made in the state vector parameters.

In the first case the object is the Apollo 8 spacecraft traveling to the moon at a velocity in excess of 4,000 ft/sec. In the second case, the object is the Apollo 8 spacecraft traveling to the earth at a velocity in excess 5,000ft/sec [14].

This quotation[15] from the NASA document Day 5 & 6: The Black Team records Apollo 8's second DSKY time update.

"121:13:08 Carr: Apollo 8, Houston. Your friendly guidance officer has got a LM vector update for you and a CMC time update. Over.
121:13:17 Borman: Okay. We'll go to P00. P00 and Accept.
121:13:29 Carr: Roger.
[Long comm break.]
Public Affairs Officer - "Apollo Control, Houston. You heard Apollo 8 crew in extremely good spirits this morning. We have a well rested Apollo 8 crew. The status report indicated that each crew member had about 7 hours sleep; breakfast to complete, the water dump in progress while you listened, and then completed. Jim Lovell confirmed that onboard numbers for midcourse corrections coincided very closely with those on the ground. And at 121 hours, 18 minutes into the flight of Apollo 8, continuing to monitor, this is Apollo Control, Houston."
121:19:56 Carr: Apollo 8, this is Houston. The updates are complete. The computer is yours. You can go to Block.
121:20:05 Borman: Roger; Block. (Long pause.)

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[13] **APOLLO 8 Mission Report MSC-PA-R-69-1** p.6-47. The several statement could include time changes in the state vector.

[14] **Julian Schwinger:** *Einstein's Legacy* (Scientific American Books, Inc. 1986). p.116. Schwinger discusses the "Twin Paradox" problem in Special Relativity, places a strobe light on earth and one on the spacecraft that is traveling to Vega and back. He states that the strobe on the spacecraft flashes faster on the trip back. Schwinger has a rather complex logical explanation for why that is to be expected and concludes only Zeus knows whether the twins are the same age when spacecraft returns to earth.

[15] **http://history.nasa.gov/ap08fj/ Day 5&6 The Black Team GET 121:13:17**. Apollo 8's altitude is 118,346 nautical miles above Earth.

121:20:50 Borman: Houston. We won't transfer that state vector, since we are not going to do that MCC Is that all right?
121:20:58 Carr: Okay. Real fine, Frank.
121:21:03 Borman: Roger.
[Comm break.]"

Apollo 10

Apollo 10's purpose was to identify a landmark and a landing sight for Apollo 11 navigation aids. During the Apollo 10 mission the astronauts and Mission Control acknowledged that there is a 1 second delay for the signal transmission.

This quotation [16] is from the NASA Document

"053:13:16 Duke: Me and the Retro can really count...
[The spacecraft is now approximately 170,000 nautical miles [315,000 km] from Earth, so any voice calls from MCC-H to synchronise mission times have to be called out earlier than the actual time to allow for the voice signal to travel at the speed of light through the MSFN network links and up to the spacecraft to be received at the intended time.]
052:13:18 Stafford: [Garble].
052:13:22 Stafford: Taking lots of lessons from Llewellyn there, huh?
052:13:25 Duke: Roger.
052:13:29 Stafford: Okay. I've got the CMC clock going. It looks Synced, here.
[The CMC clock can be displayed by calling up Verb 06 Noun 65 which shows hours in register 1, minutes in register 2 and seconds (to 0.01 secs) in register 3.]
052:13:32 Duke: Roger.
[Comm break.]
PAO: Apollo 10 is far enough out now that there's a one second delay in transmissions between the Control Center and the spacecraft and vice versa."

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[16] **history.nasa.gov/ap10fj/.** 10-day3-pt10.htm. Mission Control recognized the CM DSKY had to be set forward (it added time) 1 second to keep the beat-rate of the computer's clock and DSKY reading "GET" time when observed by mission Control just as Apollo 8.

Apollo 11

The LM landing, rendezvous with CM, and the CM return to Earth was the successful achievement of President Kennedy's goal. This was the conformation of all of NASA's careful planning and control.

However, the guidance system landed the LM ~15,000 feet down range from the proposed sight selected from the information provided by Apollo 10 mission. When the landing burn was initiated behind the moon, Neil Armstrong realized the touchdown would be down range (a guidance system's navigation error of 3 to 4 knots ~20,000 feet). Part of this navigation error resulted from the MSFN radar error in the position of the LM ~7,000 feet down-range as it passed across the face of the moon. An additional contribution could have been the time in the state vector ~1 second as measured by Apollo 10.

Armstrong was distracted from taking any corrective actions by the 1202 alarms, which indicated the computer was "failing". But, he was determined to land and understood the computer was responding to his steering commands even though it's computational capacity was being (over-loaded) by the rendezvous radar's erroneous inputs, 1202 alarms. The Lunar surface at this down range landing sight was a field of rocks requiring Neil Armstrong to maneuver the LM in the last few seconds before touchdown.

Neil Armstrong and Dr. Laning overcame the human errors made by the software designers (added the unnecessary restart routine which consumed more time), the designers of the system simulators, and the mistaken ideas (the clock was not precision) of Houston guidance system support team's claim that the 1202 Program Alarms were due to a faulty clock[17]. Fortunately, during the mission the guidance system design teams at their offices in Houston and Cambridge were monitoring the operation of the guidance system and reported, "GO" for landing.

[17] **Eldon C Hall**, ***Journey to the Moon*** **American Institute of Aeronautics and Astronautics, Inc. Reston, VA. 1996**. p.180 these errors were responsible for overshooting the "right spot " by about 3.5 knots

This quotation summarizes the Operating System and Wait List of Apollo Guidance System's Computer.

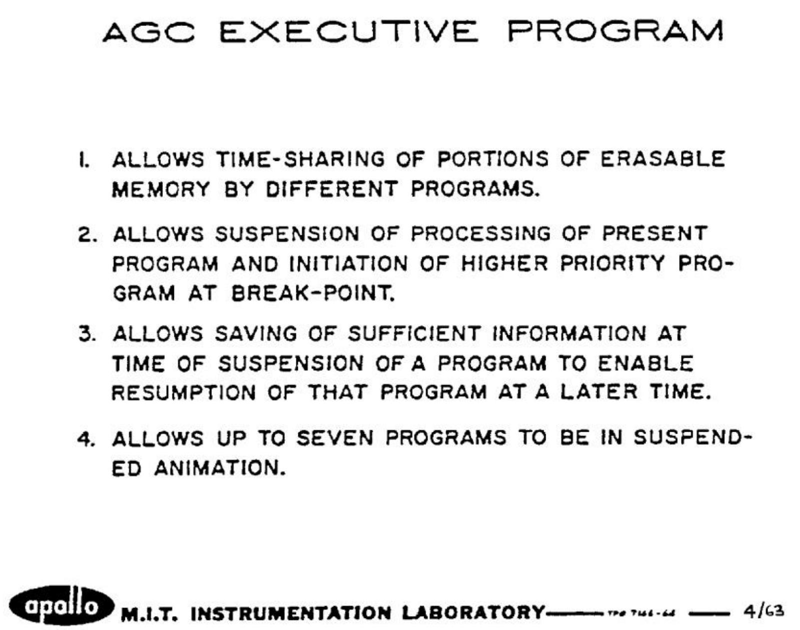
OPERATING SYSTEM

In modern software terminology, the Apollo Computer's "operating system" consisted of an Executive and Waitlist, an interpretive language, programs to manage restart and self-check, DSKY operation, and system input/output.

AGC hardware, like most digital computers, do only one operation at a time. Therefore, real-time control demanded a carefully integrated combination of hardware and software operations. Real-time control means the computer must be responsive to external stimuli from the crew or spacecraft systems and provide timely outputs for controls.

Real-time control required a priority system for computations and responses to external stimuli. For example, processing a DSKY keyboard action by an astronaut was not "real-time", but the reaction time was critical. The computer must respond to a keyboard entry with high enough priority to take action before another key is depressed.

The priority system allowed low priority task to be suspended in times of heavy real-time computations. Routines that made up the "operating system" provided this priority system and managed the AGC's resources.



AGC EXECUTIVE PROGRAM

1. ALLOWS TIME-SHARING OF PORTIONS OF ERASABLE MEMORY BY DIFFERENT PROGRAMS.
2. ALLOWS SUSPENSION OF PROCESSING OF PRESENT PROGRAM AND INITIATION OF HIGHER PRIORITY PROGRAM AT BREAK-POINT.
3. ALLOWS SAVING OF SUFFICIENT INFORMATION AT TIME OF SUSPENSION OF A PROGRAM TO ENABLE RESUMPTION OF THAT PROGRAM AT A LATER TIME.
4. ALLOWS UP TO SEVEN PROGRAMS TO BE IN SUSPENDED ANIMATION.

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FIG. 90 EXECUTIVE PROGRAM (Charles Stark Draper Laboratory Archives Graphic Number 24957)

Executive and Waitlist

The Executive and Waitlist are the heart of the operating system. Fig. 90 and Fig. 91 summarize their features.

Executive programs scheduled "Jobs" according to an assigned priority and maintained a list of eight active "Executive" jobs with each job's priority and starting memory address. Job priority assignments controlled the allocation of the computer's computational capacity to allow time-sharing among as many as eight active jobs. The active job made periodic tests for other jobs of higher priority. If the list contained a higher priority job, the active job would be suspended in favor of the higher priority job. When the suspended job becomes the highest priority on the list, processing resumed thus providing a schedule of jobs according to priority. Dummy-job was the lowest priority, just wasting time until another higher priority executive job was placed on the list.

Waitlist controlled "Tasks" that had to be completed in real-time such as a keyboard depression or an overflow from a timing counter. These actions interrupted Executive jobs and caused an involuntary transfer of control to the waitlist.

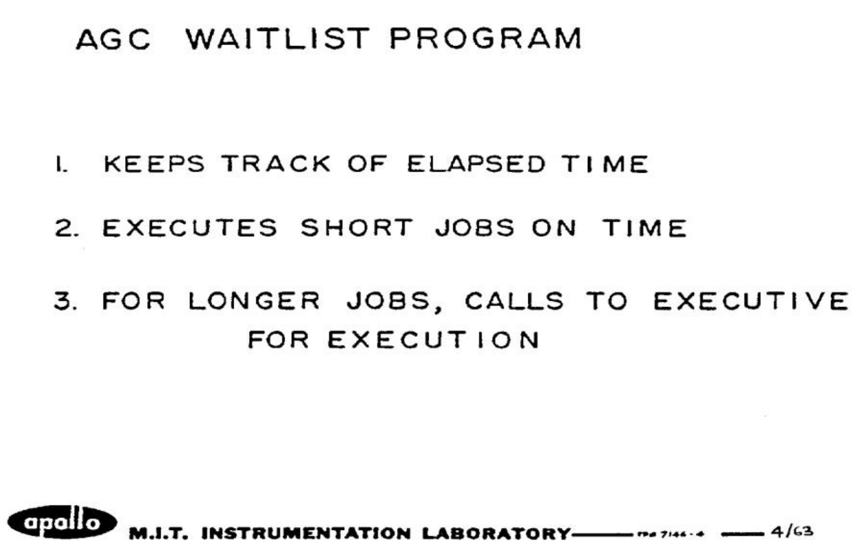

FIG. 91 WAITLIST (Charles Stark Draper Laboratory Archives Graphic Number 24954)

To set up a Waitlist task, the Executive decided when tasks should be run, stored the starting addresses and real-time intervals between active tasks in the Waitlist. A time counter was set to the time remaining before processing the next Waitlist task. The time counter counted down to zero, interrupted the active executive job, and initiated the next Waitlist task. At task completion, the time counter would be reset to the time remaining before the next task and the control returned to the Executive. Therefore, if the computer were not in the "interrupt mode" running a Waitlist task, it would be processing a job under Executive control.

Waitlist tasks were restricted to less than five milliseconds running time to avoid delaying other tasks and job priorities. In times of heavy load, the time limit ensured the most critical computations would be processed first. Thus the computer's operating system maintained a constant background of activity and responded to asynchronous inputs while supplying outputs to displays and spacecraft controls in what appeared to be a "real-time" sequence.
Although the processor executed only one operation at a time, operations were performed fast enough to keep many balls in the air."

This is a quotation[18] from the NASA Document
"102:32:03 Aldrin: (To Houston) Say again the angles, though.
102:32:05 Duke: Roger.
102:32:06 Aldrin: I'll set them in to use them before we yaw around.
102:32:08 Duke: Rog. Pitch 212, yaw plus 37. (Pause)
[They are flying with engine forward and windows down. After they finish landmark tracking to confirm their trajectory during the first few minutes of the powered descent, they will yaw the spacecraft (a rotation around the thrust axis) to put themselves in a windows-up orientation. This will be done so that, as the spacecraft pitches toward an upright orientation for the landing, they will be looking out the windows at the landing site. At 102:36:11, in the onboard comm, Neil says they've passed over the crater Maskelyne W about three seconds early and, therefore, will be landing long. In a 24 September 1969 memo, Howard Tindall discussed factors, which make pinpoint landings difficult. He cited "thrust from the LM water boiler" resulting in a 6,000 foot miss distance, or about 1/4 of the 4 miles by which Apollo 11 overflew its target.]"

The success of Apollo 11's mission was determined by the functionality of the computer's operating system that allowed the computer to continue operating even though it was over-loaded. The operating system[19] was designed many years in the past by Dr. J. Halcombe "Hal" Laning, Jr. (PhD in mathematics at MIT). He foresaw the requirement for software that would give the computer the ability to process all necessary in-flight software like the digital autopilot even though it's processing capacity was exceeded. The Apollo 11 landing helped Mission Control's navigation and guidance experts to understand the state vector (position,

[18] **https://www.hq.nasa.gov/alsj/a11/.** The 1202 program alarm is not an alarm that was seen during simulations. As Neil explained during a post-flight press conference, in simulations we have a large number of failures and we are usually spring-loaded to the abort position. And in this case real flight, we are spring-loaded to the land position.]"

[19] **Eldon C Hall**, *Journey to the Moon* American Institute of Aeronautics and Astronautics, Inc. Reston, VA. 1996 p.161

velocity, and time) computed from MSFN measurements was not correct. After Mission Control made the necessary adjustments all remaining lunar missions 12, 14, thru 17 landed right at the selected sight.

Conclusions

The magnitudes of the distance, velocity, and acceleration of the Apollo spacecraft when in the vicinity of the Moon were factors new to Apollo personnel. These factors do not appear to be considered in navigation expert's computations of state vector parameters (position and velocity). In the Apollo Program the magnitude the transmission delay was not considered until Mission Control learned to account for it after the Apollo 11 landing.

What have we learned?

1. The analysis of the Apollo 8, 10, and 11 data indicate that at these velocities the beat-rate of the computer's clock is slower when moving away from the observer and faster when moving toward an observer just as Schwinger stated in his tripe to Vega with strobe lights installed on the spacecraft. If Mission Control had not updated the DSKY read out to display "GET", the Apollo 8 computer's DSKY would have red the correct time at the moon (1.25 seconds slow as observed at Mission Control). Similarly, when the Apollo 8 spacecraft returned to earth, the clock's beat-rate would be faster and the DSKY read out would return to earth time. Schwinger has a rather complicated logical argument to discount the strobe light's operation during the return tripe. But, the Apollo spacecraft's guidance system was designed to operate independent of ground control. The computer's clock was precision and correct and should not have been updated to display "GET" for the astronauts. Time observed by the astronauts <u>within</u> the spacecraft would be the same as an Earth-based clock when observed <u>on Earth</u>.

2. Even though no attempt was made during the Apollo program to test for relativistic phenomena at these low velocities, the events recorded clearly suggest that Mission Control did observe time dilation when the DSKY was updated, non-absolute time at the LOS event, and relativistic shortening of range when the Apollo 11 spacecraft in lunar obit was ~7,000 feet down range from state vector's position as computed using MSFN data. This computation did not consider the ~1.3 seconds to account for the 250,000 nautical mile (one knot is 6076.11 feet) moon to earth transmission delay[20].

[20] **Julian Schwinger:** *Einstein's Legacy* (Scientific American Books, Inc. 1986) This is an example of relativistic contraction of length at a much lower velocity than Schwinger considers p.116.

3. The data demonstrates that Mission Control had the instrumentation to measure the CMC's beat-rate to fractions of a millisecond and that the CMC beat-rate remained stable throughout the launch and early phase of the mission[21]. However, the in-flight performance of the clock as it approached the moon was much larger than should be expected from the 0.953-milliseconds/hr slower beat-rate observed near earth.

In the first three missions, Mission Control did not understand that the MSFN spacecraft's position data produced by range measuring radar is the time required to transmit the reflection from the target to the radar transmitter (in this case ~1.25 seconds from spacecraft to ground). The velocity was computed from Doppler readings. These measurements worked well for position and velocity near earth. However, at lunar distances the transmission delays and spacecraft velocities introduced errors in MSFN data. At the moon these delays would introduce an error in range over one knot (approximately 6000 ft). The velocity determined from Doppler readings would be quite accurate because the acceleration is small which means the velocity changes slowly.

4. There would be no "Twin Paradox" [22]

Einstein's time dilation as computed from his equation

$$T/T'=\sqrt{1-(v/c)^2}.$$

is insignificant until the velocity is very close to "c"

In Einstein's lifetime, even airplanes were limited to a few hundred miles an hour. Maybe Einstein's equation will still apply as Einstein observed in his train experiments and Schwinger explained in his description of the "Twin Paradox" problem with flights to Vega.

[21] **APOLLO 8 Mission Report MSC-PA-R-69-1** p.6-47.

[22] **Julian Schwinger:** *Einstein's Legacy* (Scientific American Books, Inc. 1986) p.116.

The table below indicates the communication delay that occurs in a one-way transmission.

Circuit	**Distance**	**Delay Time**
HF link (UK-NZ)	~20,000 km	0.07 s (67 ms)
Submarine cable (UK-Z)	~20,000 km	0.07 s (67 ms)
Geosat Link (US-Aus)	~80,000 km	0.25 s
Earth-Moon	384,000 km	1.3 s
Earth-Mars	55 - 378 million km	3 - 21 minutes
Earth-Jupiter	590 - 970 million km	33 - 53 minutes
Earth-Pluto	~5800 million km	5 hours
Earth-Nearest Star	~9.5 million million km	4 years

Only the first two circuits listed have a delay that is barely noticeable in a two-way voice conversation. On telephone calls between continents that are routed via a geosynchronous satellite, the time between when one person stops speaking and then hears the other person reply is half a second. This can cause immense confusion if the other person starts speaking before the first has finished. It can take several sentences before the confusion is finally sorted out. Two-way digital communication between machines at high data rates suffers from this problem even more acutely.

Communication with a future lunar base will be worse, and for voice communications will necessitate an "over to you" simplex radio communications type approach. Two-way interactive communication with any station beyond the moon is basically impossible. Although there are no manned bases currently on other planets, this delay is presently of great concern to people who send remotely controlled spacecraft to solar system planets. There is no possibility of detecting an incipient vehicular crash in time to do anything about it. The vehicle needs to be given a very large degree of autonomous control (e.g. for navigation).

But, if we ever have manned missions traveling to more distant planets, we can essentially forget about communicating with them. This is not to say that we couldn't follow progress reports. By the time we had replied, our advice would be totally irrelevant. However, the magnitude of the velocity made significant changes to the range during each measurement.

Unless we manage to break the light barrier for information transmission, which is impossible for current physics. However, there is some experimental data in particle physics that seems to indicate information is traveling instantaneously between distant particles.

However, the magnitude of the velocity made significant changes to the range during each measurement. Distant communications are carried by radio waves, but increasingly by light. The speed of propagation of these carriers is about 300,000 kilometers per second. Digital computer designers must accommodate signal transmission time (1ft in $10^{=9}$ seconds) that is the speed of light and all other electromagnetic radiation. As we begin to contemplate interplanetary travel, we find that the finite speed of light imposes serious limitations on our activities.

More on calibration and syn. Navigation experts did not recognize the need ~~necessity~~ to calibrate or syn time in the state vector. The software designers put in the subroutine.

Range measuring radars do not measure the exact range of a moving object. They measure the time it takes for the radar signal reflected from the object to return to the radar antenna. During that period of time the object can move in any direction for a distance of (X=VT).   This fact suggests that distances measured by the radar tracking are shortened by the spacecraft's velocity.

The spacecraft's velocity is ~7,000 feet/second. MSFN Radar range measurements at a lunar range of 250,000 nautical miles and at a velocity of 7,000 feet/second was new for Mission Control's personnel when Apollo 8 flew to the moon.

Most spacecraft do not have a clock to observer.
Until information can be transmitted at infinite velocity this "fact" cannot be verified. Dr. Hal Laning was also the genius that developed the Q-Guidance System theory that made possible the digital guidance computer for the Polaris Fleet Ballistic Missiles' guidance system. [23]

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[23] **Eldon C Hall**, *Journey to the Moon* American Institute of Aeronautics and Astronautics, Inc. Reston, VA. 1996 p.39 Dr. Hal Lanning was the inventor of the Q Guidance and Control theory. The equations are in analog Fig 16 and digital Fig. 17. This approach made possible the digital differential analyzer type architecture for the Polaris Mark I Guidance System's Computer. The first guided flight was late 1959 and the system was operational in the Polaris Fleet for many years. By 1961, the Polaris Mark II guidance systems (also a digital differential analyzer) was in production.

A more serous problem for humans when they start traveling in space is the adjustment to space environment. Some experiments with plants in the space station indicate that plants can adjust to forces that simulate gravity. What about all of the other items in the food chain and even babies? Can they adjust to changes in gravity?

There are more basic questions. The Earth was created for human beings and must continue to exist. Human beings and the food chain to support them are dependent on the earth's rotation, which sets day, month, year, gravity, and atmosphere. The earth's atmosphere protects human life and all of the food chain from the gamma rays emitted by the Sun.

The Earth seems to be created for human beings and its food chain for support. Both, or at least the food chain depend on the earth's rotation, which sets the day, month, year, gravity, and atmosphere. The earth's atmosphere protects human life and all of the food chain from the gamma rays emitted by the Sun. The humans of earth also need the technology of the medical systems of earth.

Many writers that are investigating humans traveling and colonizing space do not recognize the unique conditions on earth. In the **Fall 2015 Colloquy** article, the writers appear to recognize some conditions necessary for life on earth, as we know it.[24]

[24] **Fall 2015 Colloquy:** *The* **GRADUATE SCHOOL** *of* **ARTS AND SCIENCES | HARVARD UNIVERSITY,** p. 14