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NASA'S FY2020 BUDGET REQUEST

SUMMARY

On December 20, 2019, President Trump signed into law the Consolidated Appropriations Act (H. R. 1185, P.L. 116-93), which includes the FY2020 Commerce-Justice-Science (CJS) appropriations bill that funds NASA.

The law provides $22.629 billion for NASA, very close to the amended request of $22.616 billion, although how the money is to be spent is different than requested.

The amended request was composed of **$21.019 billion** requested on March 11, 2019, plus a supplemental request on May 13 for **$1.6 billion** to fund the Artemis program to accelerate the return of astronauts to the Moon by four years – from 2028 to 2024.

The original request on March 11 for $21.019 billion was a cut of $481 million from the FY2019 enacted level of $21.500 billion. NASA Administrator Jim Bridenstine, other NASA officials, and text in NASA's budget documentation characterized it as an increase in funding, even though it was a reduction. To create their narrative, they compared it to how much Trump *requested* for FY2019, not how much was appropriated by Congress.

Just two weeks later, however, Vice President Pence directed NASA to accelerate its plans to return astronauts to the Moon, resulting in the supplemental request on May 13.

- The House Appropriations Committee reported its CJS bill, H.R. 3055, on May 22, 2019 (H. Rept. 116-101). It **passed the House on June 25, 2019** after three other appropriations bills were added to it creating a package referred to as "Minibus 2." **The House bill funded NASA at $22.315 billion**, an increase of $815 million over FY2019; $1.296 billion more than the original (March 11) budget request; and $300 million less than the amended (May 13) request. The additional money above the March 11 request mostly was to fund science and education programs the Trump Administration proposed terminating, however, not the Artemis program. The House rejected the proposed terminations and ignored the May 13 supplemental request for Artemis.
- The Senate Appropriations Committee reported its CJS bill, S. 2584, on September 26, 2019 (S. Rept. 116-127). **It funded NASA at $22.750 billion**, an increase of $1.250 billion above FY2019; $1.296 billion above the original (March 11) request; and $134.3 million above the amended (May 13) budget request. The bill funded some, but not all, of the additional money requested for Artemis. Like the House, it rejected the proposed terminations for Earth science, astrophysics, and education.

By Marcia S. Smith

- The final version of the bill, included in the Consolidated Appropriations Act (H.R. 1185), passed the House on December 17 and the Senate on December 19. It was signed into law on December 20, hours before the second of two Continuing Resolutions (CRs) that had funded the government since October 1 was about to expire. It rejects the proposed terminations in the budget request and provided some, but not all, of the supplemental request for Artemis. The biggest cut was to human lunar landers. The supplemental asked for an additional $1.045 billion (on top of $363 million in the original request). The total allocated was $600 million and 60 percent of money for that and certain other programs may not be obligated until NASA submits a plan on how it will implement Artemis.

For FY2020, NASA again displayed its request in the format used in its FY2019 request even though Congress rejected the restructuring last year. Congress rejected it again this year. With the request in one format and congressional action in another, apples-to-apples comparisons are extremely difficult for three of NASA's appropriations accounts: exploration, space operations, and space technology. Table 1 below is a best attempt.

Table 2 shows NASA's five-year "run-out" – projections through FY2024 – but they are from the original FY2020 request. The Administration has not released a run-out for the revised program including Artemis funding.

KEY ISSUES

THE ARTEMIS MOON-BY-2024 PROGRAM

On March 26, 2019, Vice President Mike Pence, in his role as chairman of the White House National Space Council, announced a new Trump Administration policy to put American astronauts – the "first woman and the next man" -- at the South Pole of the Moon by 2024.

On May 13, NASA Administrator Jim Bridenstine revealed the program's name -- Artemis.

In Greek mythology, Artemis is Apollo's twin sister. The Apollo program saw 12 men land on the Moon from 1969-1972. Naming this new program after a female underscores the Trump Administration's theme that women play a major role in the space program and one will be on the first crew to return to the Moon in 2024. (It should be noted, however, that for the first time since 2005 there are no women in any of the top jobs at NASA Headquarters.)[1]

NASA insists it is not "going back" to the Moon, but "going forward" to the Moon since it will be done differently than Apollo -- with international and commercial partners, using primarily reusable systems to ensure sustainability.

[1] Shana Dale became the first female Deputy Administrator in 2005 when Mike Griffin was Administrator during the second term of George W. Bush's Administration. She was followed by Lori Garver and Dava Newman through 2017 under Charlie Bolden during the Obama Administration. Women also have served as NASA Chief Scientist as recently as 2016. Women do hold the top jobs at two of the 10 NASA Centers –Jody Singer at Marshall Space Flight Center and Marla Pérez-Davis (Acting) at Glenn Research Center (following the resignation of Janet Kavandi) – but at HQ.

President Trump has made a number of public statements where he makes clear he has little interest in sending astronauts to the Moon, however. He wants to send them to Mars. Pence and others have convinced him that using the Moon as a "proving ground" before going to Mars is a requirement, though not everyone agrees. That includes Apollo 11 astronauts Mike Collins and Buzz Aldrin who shared their views with the President during an Oval Office visit commemorating the 50th anniversary of the Apollo 11 landing on the Moon.

NASA continues to focus on landing astronauts on the Moon nonetheless, though Pence and Bridenstine are making more of an effort to tie the Moon and Mars together and refer to Artemis as part of the "Moon to Mars" program.

Prior to March 26, NASA was planning to put astronauts on the Moon by 2028. Accelerating it to 2024 means that it would take place during the last year of a second Trump term if he wins reelection. Tying the schedule to a political milestone is controversial, but Bridenstine portrays it as reducing political risk since prior efforts to return to the Moon have failed in part because political winds changed before the programs could be completed.

Moon to Mars: 1989-2018 (SEI, Constellation, Asteroid Redirect Mission)

That is not true in every case, though. President George H. W. Bush's 1989 Space Exploration Initiative (SEI) did not die because he left office. It never garnered congressional support in the first place largely because of its estimated cost of $400-500 billion over 30 years.

It is true, however, that President George W. Bush's Constellation program to return astronauts to the Moon by 2020 and someday go to Mars was cancelled when Barack Obama became President. An independent review concluded NASA would need an additional $3 billion per year to do it and the Obama Administration was not prepared to make that investment.

Democrats and Republicans in Congress were furious. The announcement was made as part of the FY2011 budget request on February 1, 2010 with little or no advance warning. At the time, the space shuttle program was ending because of decisions made by the Bush Administration and adopted by Obama. Obama proposed nothing to replace it or Constellation. The United States was about to become dependent on Russia to take astronauts to and from the International Space Station (ISS), with no post-ISS human spaceflight program on the horizon.

Reacting to the criticism, Obama made a speech on April 15, 2010 at Kennedy Space Center where he said his goal was to send humans to Mars, bypassing the Moon since we had already been there. He promised astronauts would be in orbit around Mars in the 2030s, with landings at an unspecified time in the future. The first step would be sending astronauts to an asteroid, which eventually became the Asteroid Redirect Mission where an asteroid was to be robotically diverted into lunar orbit and studied by astronauts there.

The mid-sized Ares I and Saturn V-class Ares 5 rockets under development for Constellation were cancelled, but in the 2010 NASA Authorization Act, Congress directed NASA to build a different Saturn V-class rocket – the Space Launch System (SLS) – and a Multi-Purpose Crew Vehicle (MPCV) to send astronauts to the Moon or other "deep space" destinations. NASA chose to retain the Orion spacecraft that was already under development for Constellation as the MPCV.

Thus, during the Obama Administration, development of the rocket and crew spacecraft needed to send people anywhere beyond low Earth orbit continued at a rate of about $4 billion per year. Some argue that the only real difference between Bush's Constellation and the Obama-era SLS/Orion program was the design of the rocket and the intermediate destination – an asteroid instead of the surface of the Moon -- as a steppingstone to the ultimate goal of Mars.

Moon to Mars Today (Artemis)

Trump cancelled Obama's Asteroid Redirect Mission without fanfare or complaint soon after he was inaugurated. It had never garnered very much political or scientific support.

In December 2017, Trump issued Space Policy Directive-1 (SPD-1), restoring the Bush-era goal of putting astronauts back on the lunar surface before going to Mars.

NASA's "Architecture" for Returning to the Moon

By that point, NASA had spent six years working on the SLS and more than a decade developing Orion (since FY2006).

It also had a notional design for a Deep Space Gateway in lunar orbit to serve as a transfer point for astronauts headed to Mars. After SPD-1, it was redesignated as just "Gateway" that initially will be used as a transfer point for astronauts traveling to the lunar surface.

Under the current scenario, SLS/Orion will ferry astronauts to and from the Gateway where lunar landers will be docked waiting to take them down to the surface and back. With the acceleration of the landing from 2028 to 2024, NASA has had to adopt innovative procurement methods and will rely heavily on partnerships with the private sector.

The Gateway has been significantly scaled back for 2024, though NASA hopes to expand it later with international partners. Initially it will have just two components: a Power and Propulsion Element (PPE) and a Habitation and Logistics Outpost (HALO) with docking ports for Orion and the landers.

NASA awarded a sole-source contract to Northrop Grumman for HALO, arguing it has the only design that can be ready by 2024. It contracted with Maxar Technologies for the PPE, which Maxar will build, launch and own for a one-year period while it undergoes in-space flight tests. NASA has the option of buying it thereafter.

The Human Landing Systems (HLS) will be owned by the companies that win the contracts. NASA will simply procure services from them to ferry astronauts to and from the surface, just as it purchases commercial cargo and commercial crew services today for going back and forth to the International Space Station (ISS). NASA has a notional HLS design that involves three elements: a Transfer Vehicle to take the crew to a lower orbit than the Gateway can reach, a Descent Vehicle to reach the surface, and an Ascent Vehicle to return to the Gateway. Companies can propose their own designs, however, and Boeing, for example, argues that NASA's concept is too complicated and is proposing something entirely different. NASA hopes to award contracts for HLS in January 2020.

Under NASA's plan, the PPE, HALO, and HLS systems will be launched by commercial rockets, not SLS. SLS will be used only to launch crews. As discussed below, congressional appropriators have a different idea and require NASA to submit a plan to execute Artemis that includes using SLS to "build" Gateway, not just take crews there.

Space Launch System Delays Have Unexpected Impact

Before Pence's March 26 directive, SLS prime contractor Boeing notified NASA of yet another SLS delay. The first launch, a test flight without a crew, was originally scheduled for November 2018 but already had slipped to December 2019-June 2020. Now it would be delayed again.

NASA and the White House did not take the news lightly. Bridenstine told the Senate Commerce, Science, and Transportation Committee, which authorizes NASA's activities, on March 13 that the agency was looking at commercial alternatives to SLS such as SpaceX's Falcon Heavy. Considering that the SLS program is managed at NASA's Marshall Space Flight Center in Huntsville, AL, and the senior Senator from Alabama, Richard Shelby (R), chairs the Senate Appropriations Committee and is an unabashed supporter of SLS, the action seemed politically doomed from the start.

Then, on March 26, Pence spoke at Marshall at a meeting of the National Space Council. In another surprise move, he announced an acceleration, not a delay, in the Moon program, moving the landing date up by four years to 2024. Without naming Boeing, Pence issued strong words of warning that contractors who could not meet that schedule would be replaced. He was equally direct with NASA – if the agency could not meet that date, the agency, not the goal, would have to change.

Despite the rhetoric, NASA quickly concluded it was not technically viable (never mind politically) to replace SLS with commercial rockets for launching crews and still meet the 2024 schedule.

The SLS is composed of a core stage, two solid rocket boosters on the sides, and an upper stage (initially the Interim Cryogenic Propulsion Stage, ICPS, and later a more powerful Exploration Upper Stage, EUS).

The core stage is proving more difficult to build than Boeing or NASA imagined. They began trying to find ways to save time, some of which proved controversial. In particular, the idea was broached to shorten or eliminate the "Green Run" test where all four engines would be integrated into the core stage and fired for the full 8 minutes they will have to work during an actual launch.

NASA's Aerospace Safety Advisory Panel strongly and repeatedly urged NASA to retain the test. On July 25, 2019, Bridenstine conceded and said the test would take place. His decision was a surprise because just 15 days earlier he had dismissed the head of NASA's Human Exploration and Operations Mission Directorate (HEOMD), Bill Gerstenmaier, and his deputy who oversaw SLS and Orion, Bill Hill. At the time Bridenstine said no decisions would be made about the test or other SLS/Orion matters until their replacements were hired and had an opportunity to review the situation.

Why he changed his mind and made the decision himself is unclear, but it was widely welcomed. The only place it can be conducted is on the enormous test stands at NASA's Stennis Space

Center in Mississippi. The chairman of the Senate Commerce, Science, and Transportation Committee, which oversees NASA, is Sen. Roger Wicker (R-MS).

On October 16, 2019, Bridenstine announced that Doug Loverro would replace Gerstenmaier. A retired Air Force Colonel, Loverro is well known and respected in the national security space community though he does not have experience in civil space programs. He reported for duty at NASA on December 3.

The date for the first (uncrewed) SLS/Orion test remains uncertain. NASA officials have said they are working to an internal date at the end of 2020, but Bridenstine told a Senate committee in July 2019 it would be 2021.

The Question of Cost

In the meantime, NASA is trying to win support from Congress to pay for accelerating the lunar landing deadline from 2028 to 2024. That is a challenge because the Trump Administration will not tell Congress how much it will cost.

Bridenstine told a congressional committee on April 2, 2019, a week after Pence's speech, that he would submit a budget amendment by April 15. It was not provided until May 13, however, just four days before the House Appropriations Committee was to begin marking up the FY2020 CJS bill.

The supplemental request, $1,596.8 million (usually rounded to $1.6 billion), is only for FY2020. It is composed of the following changes to the March 11 request.[2]

- $1,044.8 million additional for lunar landers capable of supporting humans (Human Landing Systems – HLS, labeled "Cislunar/Surface Capabilities" in the budget)
- $140.5 million additional for Orion
- $510.5 million additional for SLS
- $132 million additional for exploration technology
- $90 million additional for robotic lunar landers in the Science Mission Directorate
- A reduction of $321 million from Gateway, which is being substantially downsized for 2024 although it may evolve in the future

No estimates for the other four years, FY2021-2024, were provided. Bridenstine told the Senate Commerce committee in July that Congress must wait until the President submits the FY2021 budget request in February 2020 and repeated that at a House Appropriations Commerce-Justice-Science subcommittee hearing on October 16.

Previously he had told CNN the acceleration would cost $20-30 billion over 5 years (FY2020-2024). He later said it could be less than $20 billion depending on how much the private sector is willing to pay through public-private partnerships (PPPs), but in December 2019 told CNN again that the $20-30 billion is his ballpark estimate.

As it acted on FY2020 appropriations, Congress knew only that $1.6 billion more is needed just for the first year. At the October 16 CJS hearing, subcommittee chairman José Serrano (D-NY)

[2] These figures were obtained from NASA on October 8, 2019. They are more precise than what was released in May.

said "unless we know what this will cost at the end, it will be irresponsible for us to take the first step."

Bridenstine repeatedly acknowledges that taking money from other parts of NASA to pay for Artemis will create partisan and parochial discord that will doom the program.[3] That means the money would be in addition to what NASA planned to request in those years – roughly $21-22 billion annually.

While he was still head of HEOMD, Bill Gerstenmaier told the NASA Advisory Council (NAC) that he knew how much new money is needed for Artemis, but he also knew NASA would not be getting it all as an addition to its top line. Formulating the $1.6 billion supplemental request was "easy," he said, because no money was taken from other NASA programs and it was spread around. Some went to science and some to space technology. He did not expect that to be true in the future.

> *When we get to [FY2021], I don't think we're going to be able to get the entire budget as new money to the topline. We're gonna have to look at efficiencies and a mix of cuts internal to the agency. That's where it's going to be hard." NASA's Bill Gerstenmaier, May 31, 2019*

The House Appropriations Committee totally ignored the supplemental request and addressed only what was in the original March 11 request, which included funding for the lunar program as it existed then with a landing in 2028. The Administration's request was a reduction from what Congress appropriated for FY2019, with cuts proposed to all NASA programs, including SLS and Orion, except technology to support the lunar program.

The committee criticized NASA for prioritizing human spaceflight over science and education. It increased NASA's total budget compared to the March 11 request, with the biggest boost going to science (see Table 1). The House passed the bill with only minor changes on June 25, 2019.

At a July 24 hearing about the White House Office of Science and Technology Policy (OSTP), CJS subcommittee chairman Serrano made clear that he supports the goal of returning astronauts to the Moon, but is not persuaded that the deadline needs to be accelerated to 2024. He asked OSTP Director Kelvin Droegemeier if it is "technically possible, financially responsible, or necessary, to launch the manned Moon mission four years early at an additional $20 billion cost just to meet a geopolitical deadline." Droegemeier demurred, saying it was a question for NASA. That led to the October 16 hearing with Bridenstine where Serrano reiterated his doubts.

The Senate Appropriations Committee provided some, but not all, of the supplemental request for Artemis. It told NASA it could not assess the implications for other NASA programs until NASA provides a 5-year budget plan for all Artemis activities and until then would provide funds only to "advance" the program.

[3] Directly contradicting Bridenstine's statement, in the May 13 budget amendment the Trump Administration specifically asked Congress to give the NASA Administrator authority to move money within NASA to pay for Artemis. Neither the House nor the Senate Appropriations Committee approved it.

The committee then cut the amount of funding the Administration wanted for lunar landers and the Gateway and added money for building the **Exploration Upper Stage (EUS)** for SLS, which the Administration does not want now. The Administration wants to defer work on EUS so NASA and SLS prime contractor Boeing can focus on getting the initial version of SLS done. Boeing is also the prime contractor for EUS.

The amended request for human-capable lunar landers was $1.408 billion: $363 million in the March 11 request plus $1.045 billion in the May 13 supplemental. The committee provided $744.1 million of which $44.1 million is for the program office at Marshall Space Flight Center. That left $700 million for landers, less than half the request. The committee allocated $500 million for Gateway, $320 million less than the original request, but the same as the amended request. By contrast, it added $300 million for EUS even though that request was zero.

SLS and EUS are managed at Marshall, in Huntsville, AL. As noted, that is the home state of Sen. Richard Shelby who chairs the Senate Appropriations Committee. NASA's current plan for Artemis uses SLS only for launching crews, with Gateway elements and landers launched on commercial rockets.

Shelby is an avid advocate for SLS and an alternative architecture is to defer Gateway and rely on SLS/EUS to launch everything. That proposal was explained to the House Science, Space, and Technology Committee on September 18, 2019 by Doug Cooke. Cooke had a long career at NASA and headed the Exploration Systems Mission Directorate from 2008-2011 (which later was merged into HEOMD). He now is a consultant and Boeing is one of his clients. He said the NASA plan, using Gateway, "makes no sense" although he agreed Gateway could be useful in the future for Mars missions. The Senate committee report did not reference this alternative pla in its report on the bill, but its actions appear aligned with it. As noted below, the report accompanying the final version of the bill requires NASA to submit a plan on how it will use SLS to "build" Gateway. NASA's plan is to use commercial rockets to build Gateway, not SLS.

Lukewarm Support for Artemis in the Final FY2020 Appropriations Bill

The House and Senate committees that oversee NASA agree with the overarching goal of sending astronauts to the Moon and Mars. The debate is over how, and how quickly, to do it. Neither the House nor the Senate appear to be in the same hurry as the White House.

Key to achieving the goal is the HLS system, or systems since Bridenstine wants to have at least two in development in case one encounters development problems. The final bill provides only $600 million, however, less than the $744 million allocated by the Senate Appropriations Committee, and less than half the $1.4 billion requested. Unless the companies themselves agree to put in substantial sums of money themselves as part of these public-private partnerships, it seems unlikely that the 2024 deadline can be met.

Other components of the Artemis program had mixed fates. In summary:

- SLS received $2.586 billion, $300 million more than the amended request. The extra money is for EUS. The request was zero since NASA wanted to defer it.
- Orion received $1.407 billion, the same as the amended request.
- Exploration Ground Systems – the infrastructure needed to launch SLS/Orion – received $590 million, $190 million more than the request.

- Gateway received $450 million, $50 million less than the amended request, which was already a $321 million reduction from the original March 11 request.
- Human Landing Systems received $600 million, less than half the $1.4 billion amended request.
- Robotic landing systems (the Commercial Lunar Payload Services or CLPS program) received $170 million. It is part of the Lunar Discovery and Exploration Program (LDEP) in the Science Mission Directorate, which also funds operation of NASA's robotic Lunar Reconnaissance Orbiter (LRO) that has been in orbit around the Moon since 2009. The total allocated for LDEP was $300 million, $90 million more than the request.

Just as importantly, bill language fences 60 percent of the funds for Gateway, HLS, LDEP (excluding LRO) and NASA's "commercial LEO" efforts to encourage companies to build space stations in Earth orbit. That means only 40 percent of the funds for those activities may be obligated until NASA submits a multi-year plan with details of how it will execute the Artemis program. The plan must include required funding and milestones by fiscal year, and estimated dates for SLS flights "to build the Gateway." NASA is not planning to use SLS to build the Gateway, but commercial rockets instead.

Furthermore, report language directs NASA to "prioritize" the selection of HLS designs "which reduce risk to schedule and engineering, and above all, life." That could be interpreted as a preference for systems that use or are derived from existing designs rather than entrepreneurial approaches.

All in all, the appropriations bill and accompanying explanatory report provide lukewarm support at best for Artemis, and the name Artemis does not even appear in either.

SCIENCE

The FY2020 request continued the Administration's effort to terminate some of NASA's Earth science, astrophysics, and education programs despite Congress rejecting those attempts for the past two years. Congress rejected them again this year.

The Administration and Congress also disagree on some aspects of robotic missions to Jupiter's moon Europa – Europa Clipper and Europa Lander -- especially what rocket will be used to launch them. Congress directs in bill language that SLS launch both, but NASA wants to purchase commercial launch services, which are substantially less expensive, but the trip would take longer since they are not as powerful as SLS.

Earth Science

In FY2020, the Administration once again proposed terminating the PACE and CLARREO-Pathfinder Earth science missions, as well as NASA's Carbon Monitoring System program.[4]

[4] For the prior two years, the Trump Administration also tried to cancel OCO-3 and the Earth-facing instruments on the DSCOVR spacecraft. Congress did not agree. OCO-3 was launched in April 2019. DSCOVR has been in space since 2015 and the proposal was to turn off two of its instruments for political reasons (they originated with then-Vice President Al Gore).

- **PACE,** the Plankton, Aerosol, Clouds and Ocean Ecosystem spacecraft, will provide high quality global observations about ocean health and its relationship to airborne particles and clouds. Among other things, the data will be used for fisheries management and responding to harmful algae blooms. Launch is currently planned for 2022-2023. PACE is being built and tested at NASA's Goddard Space Flight Center in Greenbelt, MD.

- **CLARREO Pathfinder** will be attached to the International Space Station (ISS). CLARREO is the Climate Absolute Radiance and Refractivity Observatory. In 2016, a decision was made to focus on a technology demonstration mission first – CLARREO Pathfinder, a Reflected Solar Spectrometer that will be attached to the ISS around 2023. CLARREO Pathfinder is managed by NASA's Langley Research Center in Hampton, VA.

- **Carbon Monitoring System**. The $10 million/year CMS program, created by Congress in the report to accompany the FY2010 Consolidated Appropriations bill (P.L. 111-117, H. Rept. 111-366), primarily funds grants to help develop the capacity to monitor, report and verify biogeochemical processes to better understand the major factors driving climate change. The Trump Administration tried to end the program after Congress failed to explicitly fund it in the FY2018 appropriations bill, but Congress did explicitly fund it in FY2019.

The House Appropriations Committee rejected the proposed terminations. Instead it increased funding for NASA's Earth science program from the $1,779.8 million requested to $2,023.1 million. It restored $147 million for PACE, $26 million for CLARREO-Pathfinder, and $10 million for CMS.

The Senate Appropriations Committee also rejected those terminations, allocating $1.9 billion for Earth science, including $161 million for PACE, $18 million for CLARREO-Pathfinder, and $10 million for CMS.

The final appropriations bill provided $1.972 billion for Earth science, funding PACE at $131 million (less than the House and Senate committees recommended), CLARREO-Pathfinder at $26 million (the same as the House-recommended level), and CMS at $10 million. It also specified $1.7 million for DSCOVR, a spacecraft already sending back data about the Earth from the Sun-Earth L1 Lagrange point a million miles from Earth. The Trump Administration has previously tried to turn off the two NASA sensors that are on DSCOVR (the other two belong to NOAA).

Astrophysics: WFIRST

The Trump Administration tried again, and failed again, to cancel the Wide-Field Infrared Survey Telescope (WFIRST), the follow-on to the James Webb Space Telescope (JWST), which itself is the follow-on to the Hubble Space Telescope. WFIRST's purpose is to advance research into dark energy and dark matter and discover new planets orbiting other stars (exoplanets).

NASA's priorities for astronomy and astrophysics, as well as other space and Earth science disciplines, are set by Decadal Surveys performed every 10 years (a decade) by expert

committees established by the National Academies of Sciences, Engineering, and Medicine. WFIRST was identified as the top priority for a large "flagship" space telescope by the most recent Decadal in 2010. Its initiation was delayed because the money designated for WFIRST had to be reallocated to pay for cost overruns on JWST.

WFIRST has encountered its own challenges largely due to design changes dictated by NASA in excess of what the Academies recommended, but support in the scientific community remains strong. (See last year's report on the FY2019 NASA budget request for more information on WFIRST and JWST.)

When the Trump Administration proposed terminating WFIRST last year, it said the money was needed instead for the human exploration program to return astronauts to the Moon (expected in 2028 at that time), although some would fund smaller astrophysics programs. This year, NASA officials attributed the decision both to the need to pay for the Moon program as well as ever increasing costs of JWST, which breached its $8 billion development budget cap by 10 percent in 2018.

Congress again rejected the proposal to terminate WFIRST. The House Appropriations Committee provided $510.7 million to keep it on track for launch in 2025 or 2026. The Senate committee allocated $445.7 million. At a meeting of the interagency Astronomy and Astrophysics Advisory Committee (AAAC) on September 26, 2019, NASA astrophysics division director Paul Hertz had said that if Congress approved the lower amount recommended by the Senate, it would mean a program cost increase of about $200 million and a launch delay of about 1 year.

The final bill provided $510.7 million as passed by the House. Of that total, $65 million is for coronagraph technology development. The accompanying explanatory report also restates the $3.2 billion cost cap Congress previously imposed on the program.

Planetary Science: Europa

Planetary science was a top priority of Rep. John Culberson (R-TX), who chaired the House Appropriations CJS subcommittee for four years before losing his reelection race in 2018. During his time as chairman, he required NASA to begin a program to send two spacecraft – an orbiter and a lander – to Jupiter's moon Europa, which some scientists believe has a liquid ocean under an icy crust that may have the conditions to harbor microbial life.

NASA did not plan to build any Europa missions, but Congress has the power of the purse and Culberson convinced his colleagues to direct NASA to do so. He actually wrote into law, not just in report language as is common, that Europa Clipper (the orbiter) had to be launched by 2023 on the Space Launch System (SLS), and a Europa Lander by 2025 also on SLS.[5] Culberson proudly would say that they are the only two NASA missions that must be built and launched by law. (Report language is directive, but does not have the force of law.)

NASA reluctantly agreed to build Europa Clipper and it is under development, but it has not agreed to build Europa Lander. It also will not commit to using SLS as the rocket, since it is very

[5] Originally the dates were 2022 and 2024, but by the time of the FY2019 appropriations act, they slipped by one year each. In the FY2020 appropriations act, they slip again, to 2025 and 2027 respectively.

expensive. NASA says in its FY2020 budget request that it will launch Europa Clipper in 2023, as required, but wants to use a commercial rocket, asserting it will save $700 million. NASA officials also agree, however, that they will follow the law.

The White House Office of Management and Budget (OMB) went further in an October 23, 2019 letter to Senate appropriators. It estimated the cost of an SLS launch at $2 billion, $1.5 billion more than a commercial launch.

With Democrats now in control of the House, Rep. José Serrano (D-NY) chairs the CJS subcommittee. His enthusiasm for the Europa missions appears to parallel Culberson's. (Serrano was the Ranking Member when Culberson was chair. Culberson is now a lobbyist who told Politico that he intends to lobby on behalf of the NASA missions he advocated in Congress.)

The House Appropriations Committee again directed NASA to build both Europa Clipper and Europa Lander, and again included in the law that they be launched by SLS in 2023 and 2025 respectively. The committee provided the requested funding levels for the two missions: $592.6 million for Clipper and zero for the Lander. It explained that the $195 million appropriated for the Lander in FY2019 was sufficient also for FY2020, but it expects NASA to provide adequate funding in FY2021 and beyond. During markup, Rep. Kay Granger (R-TX), the top Republican on the full Appropriations Committee, expressed concern that no funding for the Lander was included in the bill.

The Senate Appropriations Committee did not weigh in on the Europa mission other than to insist, in the bill itself, that it be launched on SLS.

The final bill ignored OMB's complaint that each SLS launch is $1.5 billion more than a commercial launch and restates that both Europa Clipper and Europa Lander be launched on SLS. They slipped the launch dates to 2025 and 2027 respectively. The bill allocated $592.6 million for Europa Clipper. It did not specify an amount for Europa Lander, but made clear that NASA must build it.

NASA'S OFFICE OF STEM ENGAGEMENT

NASA funds education activities both through its Office of STEM Engagement (formerly the Office of Education) and as part of science missions in the Science Mission Directorate (SMD). Generally speaking, these efforts are part of an effort to encourage students to study Science, Technology, Engineering and Math (STEM) fields, which has been supported on a bipartisan basis in the White House and Congress for many years.

The Trump Administration, however, tried to eliminate NASA's Office of Education and its programs in FY2018, FY2019, and FY2020. The effort was soundly rejected by Congress (which renamed it STEM Engagement) each time.

The four programs within this office are:

- **National Space Grant and Fellowship Program**, a national network of 850 affiliates in colleges, universities, industry, museums, science centers, and state and local agencies in all 50 states plus the District of Columbia and Puerto Rico that fund fellowships and scholarships for students in STEM fields.

- **Experimental Program to Stimulate Competitive Research (EPSCoR)** that provides seed funding to enable 27 jurisdictions (24 states plus Guam, Puerto Rico and the U.S. Virgin Islands) to develop academic research enterprises directed toward long-term, self-sustaining, nationally-competitive capabilities in aerospace and aerospace-related research.
- **Minority University Research and Education Program (MUREP)** that enhances the capabilities of Historically Black Colleges and Universities (HBCUs), Hispanic Serving Institutions (HSIs), and Tribal Colleges and Universities (TCUs) through grants with the goal of recruiting underrepresented and underserved students into STEM fields through completion of undergraduate or graduate degrees.
- **STEM Education and Accountability Projects (SEAP)** for internal and external innovative education programs by NASA Centers, the Jet Propulsion Laboratory (JPL), and third parties.

The House Appropriations Committee again rejected the proposal to eliminate these activities. The committee approved a total of $123 million: $48 million for Space Grant; $25 million for EPSCoR; $37 million for MUREP; and $13 million for SEAP.

The Senate committee also rejected the proposal. It approved $112 million: $47 million for Space Grant; $22 million for EPSCoR; $33 million for MUREP; and $10 million for SEAP.

The final bill approved a total of $120 million: $48 million for Space Grant, $24 million for EPSCoR; $36 million for MUREP; and $12 million for SEAP.

NASA BUDGET AND AGENCY REORGANIZATION

NASA again proposed a change in its budget account structure even though Congress rejected it for FY2019. The proposal this year was slightly different, but fundamentally was intended to separate human spaceflight operations in low Earth orbit (e.g. the International Space plus efforts to encourage companies to build new LEO space facilities) from the development of systems to send humans beyond LEO. Currently both development and operations are managed by the Human Exploration and Operations Mission Directorate (HEOMD).

Last year, the proposal included elimination of NASA's Space Technology Mission Directorate (STMD), created by the Obama Administration to focus attention on developing cross-cutting technologies that are applicable to human spaceflight, science, or aeronautics rather than mission specific. The restructuring would have redirected most of the money into technology specifically for human spaceflight.

The new NASA-preferred budget accounts are shown in Tables 1 and 2 since that is how it presented its budget. NASA wanted to remix the Exploration and Space Operations accounts and what it wants to keep of STMD into three new accounts:

- **Deep Space Exploration Systems**, combining much of what was in the old Exploration account (SLS, Orion, Exploration Ground Systems) with Advanced Exploration Systems, including new activities associated with Artemis;
- **Exploration Technology**, essentially what remains of STMD (last year the proposal included merging Exploration Research and Development into this account, but NASA has dropped that aspect); and

- **LEO and Space Flight Operations**, combining what previously was in the Space Flight Operations account plus the new Commercial LEO Development line item to help commercial companies building LEO infrastructure.

In an unmistakable symbolic change, all three human exploration accounts are listed ahead of science, which has been first since FY2004.

Congress rejected both the proposal to eliminate STMD and the budget restructuring last year. They rejected it again this year. The House specifically states that STMD is to remain a "standalone entity within the agency." Indeed, a number of projects funded in STMD are of special interest to members of Congress from districts or states where the work on them is done, such as the Restore-L satellite servicing technology demonstration project and nuclear thermal propulsion development.

In separating human spaceflight operations from development, NASA wanted to create a new Mission Directorate and name it the "Moon to Mars Mission Directorate." It essentially was a return to how NASA HQ previously was organized when there was a Space Operations Mission Directorate and an Exploration Systems Mission Directorate. They were merged to form HEOMD in 2011.

The congressional appropriations committees indicated to NASA in May 2019 that they would not approve such a move, however. NASA is now considering a reorganization within HEOMD. The Senate Appropriations Committee, however, encouraged NASA not to disrupt its organization and instead use the Office of Chief Scientist and Office of Chief Technologist as models of how to coordinate across the agency.

OTHER ISSUES

There are some similarities and many differences between the House and Senate bills, and between those and the Administration's request. It is impractical to list them all, but key items include the following.

The House and Senate bills, and the final bill, continue the restrictions on **civil space cooperation with China**. They apply to NASA, OSTP and the White House National Space Council.

The House and Senate bills provide the requested $160 million for **planetary defense** -- finding Near Earth Objects (NEOs, asteroids and comets) that might impact Earth and testing methods to deflect them. The House specifically expressed support for the **NEOCam** mission, a proposed infrared space telescope dedicated to the search for NEOs. NASA did not request money for NEOCam, but in September 2019 the head of the Science Mission Directorate, Thomas Zurbuchen, said he will in the future. He renamed it the NEO Surveillance Mission (NEOSM). The final bill designates $35.6 million in the planetary defense budget for NEOSM.

The Senate provided more than requested for the **James Webb Space Telescope (JWST**). The committee said it was "befuddled" why NASA asked for less than it told Congress last year it needed to ensure JWST launches in 2021. The program has experienced repeated cost increases and schedule delays. Last year it breached an $8 billion cost cap Congress put into law and launch was delayed from October 2018 to March 2021. Congress increased the cost cap to the

new estimate of $8.8 billion (for development, not operations). NASA said it would need $423 million in FY2020 to make the March 2021 launch date, but requested only $352.6 million. The Senate committee allocated the $423 million. The final bill provides $423 million.

NASA requested $150 million to support efforts to encourage and facilitate companies to build **commercial space stations in low Earth orbit (LEO)**. The idea is that the International Space Station will not last forever and is very expensive. Instead of the government building another one, NASA wants to be able to lease capacity from commercially owned and operated space stations. Demonstrating there is a commercial market for LEO facilities beyond what NASA would pay for is a challenge, however. This NASA effort is intended to help. The Senate committee, however, provided only $15 million. The House committee said only that it supports public-private partnerships to advance commercial capabilities in LEO without specifying a dollar amount. The final bill follows the Senate's lead and provides only $15 million, one-tenth of the request.

The House and Senate provide money for a robotic **Mars Sample Return (MSR)** mission for launch in 2026. The House added $23.5 million to the request for Mars exploration to pay for it. The Senate did not specify the amount. NASA's next Mars probe is the Mars 2020 rover. Among other things it will collect and store ("cache") samples for return to Earth. NASA does not have a mission to actually bring them here, though. MSR would so that, but the cost and schedule for such a mission has not been determined. The final bill and report do not specifically address this mission, but language in the House or Senate committee reports not changed by this report on the final bill is approved, so the $23.5 million for MSR is there.

The House added $125 million for the development of **nuclear thermal propulsion**, $25 million more than FY2019. The request was zero. The Senate provided $100 million, of which $70 million is for the design of the flight demonstration by 2024. The final version approves $110 million of which $80 million is for the design of a flight demonstration by 2024.

The House and Senate provided $180 million for the **RESTORE-L** project to develop and demonstrate technologies to refuel the Landsat-7 spacecraft, an increase of $134.7 million above the request. The Administration wants to restructure the program to do only technology development, not a demonstration, and cut the requested funding commensurately. Congress is taking the opposite approach, expanding what the mission will do. The report accompanying the final bill notes that RESTORE-L will carry the SPace Infrastructure DExterous Robot (SPIDER) as a secondary payload so the mission will demonstrate not only satellite servicing, but in-space manufacturing. Congress provided $227.2 million for the combined program, of which no less than $180 million is for RESTORE-L specifically.

Table 1: NASA's FY2020 Budget Request

(in $ millions, see notes below)

		FY2020 Request			Appropriations		
Account (Note 2)	**FY2019 Op Plan Note 5**	**FY2020 Initial**	**FY2020 Suppl Note 4**	**FY2020 Revised**	**House-passed**	**Senate-passed**	**Final**
Deep Space Expl Syst	**5,050.8**	**5,021.7**	**+1,374.8**	**6,396.4**	Note 3 **5,129.9**	**6,222.6**	**6,017.6**
Expl Sys Development	*4,092.8*	*3,441.7*			*4,167.8*	*4,582.6*	*4,582.6*
(Orion)	*(1,350.0)*	*(1,266.2)*	*(+140.5)*	*(1,406.7)*	*(1,425.0)*	*(1,406.7)*	*(1,406.7)*
(SLS)	*(2,150.0)*	*(1,775.4)*	*(+510.5)*	*(2,285.9)*	*(2,150.0)*	*(2,585.9)*	*(2,585.9)*
(Expl Grnd Sys)	*(592.8)*	*(400.1)*			*(592.8)*	*(590.0)*	*(590.0)*
Exploration R&D	*958.0*	*1,580.0*	*+723.9*	*2,303.9*	Note 3 *962.1*	*1,640.0*	*1,435.0*
(Ady Expl Systems)	*331.5*	*(255.6)*				*(255.6)*	*(245.0)*
(Cislunar/Surf Capblty)	*116.5*	*(363.0)*	*(+1,044.8)*	*(1,407.8)*		*(744.1)*	*(600.0)*
(Gateway)	*365.0*	*(821.4)*	*(-321.0)*	*(500.4)*		*(500.3)*	*(450.0)*
(Human Rsrch Prog)	*145.0*	*(140.0)*				*(140.0)*	*(140.0)*
Exploration Technology	**926.9**	**1,014.3**	**+132.0**	**1,146.3**	Note 3 **1,291.6**	Note 3 **1,076.4**	Note 3 **1,100.0**
LEO & Spcflt Ops	**4,640.9**	**4,285.7**			Note 3 **4,285.7**	Note 3 **4,150.0**	**4,140.2**
ISS	*1,490.3*	*1,458.2*			*N/A*	*N/A*	*N/A*
Space Trans (for ISS)	*2,109.7*	*1,828.6*			*N/A*	*N/A*	*N/A*
Space & Flt Spprt	*1,000.9*	*848.9*			*N/A*	*N/A*	*N/A*
Cmrcl LEO Developmnt	*40.0*	*150.0*			*N/A*	*15.0*	*15.0*
Science	**6,895.6**	**6,303.7**	**+90.0**	**6,393.7**	**7,161.3**	**6,905.7**	**7,138.9**
Earth Science	*1,931.0*	*1,779.8*			*2,023.1*	*1,945.0*	*1,971.8*
Planetary	*2,748.4*	*2,622.1*			*2,713.4*	*2,631.1*	*2,713.4*
Astrophysics	*1,191.6*	*844.8*			*1,367.7*	*1,171.6*	*1,306.2*
JWST	*304.6*	*352.6*			*352.6*	*423.0*	*423.0*
Heliophysics	*720.0*	*704.5*			*704.5*	*735.0*	*724.5*
Aeronautics	**719.2**	**666.9**			**700.0**	**783.9**	**783.9**
STEM Engagement	**110.0**	**0.0**			**123.0**	**112.0**	**120.0**
Safety, Security, MS	**2,755.0**	**3,084.6**			**3,084.6**	**2,934.8**	**2,913.3**
CECR	**362.3**	**600.4**			**497.2**	**524.4**	**373.4**
Inspector General	**39.3**	**41.7**			**41.7**	**40.0**	**41.7**
TOTAL	**21,500.0**	**21,019.0**	**1,596.8**	**22,615.8**	**22,315.0**	**22,750.0**	**22,629.0**

Note 1: Sources: Request: NASA FY2020 budget documentation available on NASA's budget website and FY2020 Supplemental Budget Request May 13, 2019 (available on OMB's website). Congressional action: congressional bills and reports.
Columns may not add due to rounding. Text and numbers in *italics* are subtotals. Text and numbers in (*italics in parentheses*) are sub-subtotals.

N/A = not applicable or not available.
CECR = Construction and Environmental Compliance and Restoration. The "Cislunar/Surface Capability" line funds the Human Landing System (HLS).
Note 2: NASA reconfigured its budget accounts in its FY2019 request, but Congress rejected that request. Nonetheless, NASA again presented its FY2020 request in the new format. The House and Senate Appropriations Committees rejected the new structure again this year. Thus, it is difficult to compare the requested budget with congressional action on it some accounts as explained in Note 3.
Note 3: As explained in Note 2, the House and Senate Appropriations Committees use NASA's original account structure. The content of the budget line items may not be identical between what NASA requested and Congress is appropriating as shown in this table. For example, the House and Senate Appropriations bills have an "Exploration" account, a "Space Technology" account, and a "Space Operations" account, instead of "Deep Space Exploration Systems," "Exploration Technology," and "LEO and Spaceflight Operations." The proposed funding amounts at the top level appear to match with the accounts as shown in the table, but insufficient data is available publicly to know how it breaks down at lower levels. This table represents a best guess, which is all that is possible from publicly available material.
Note 4: NASA released general information about its May 13, 2019 supplemental request, but it was not detailed enough to include in this chart. We obtained the more detailed numbers shown here from NASA (Sean Potter) via email on October 8, 2019.
Note 5: NASA submits operating plans to Congress to show how it plans to spend the money Congress appropriated. Congress may disapprove the plan if it disagrees, but eventually each year a final plan is adopted. The operating plan amounts may not be the same as those that were enacted in the appropriations bill. The figures in this column are from NASA's Initial Operating Plan dated June 2019, which is the only public document available as of the date of this report, but there likely were changes after that. The final numbers typically are not known publicly until the next year's budget request is submitted.

Table 2: Projected NASA Budget FY2020-2024 (Out-Years) in March 11, 2019 Budget Request
(in $ millions, does NOT reflect the Artemis program)

Account	President's Request	Projections			
	FY2020	FY2021	FY2022	FY2023	FY2024
Deep Space Expl Syst	**5,021.7**	**5,295.5**	**5,481.4**	**6.639.0**	**7,012.3**
Expl Sys Development	*3,441.7*	*3,111.0*	*3,168.4*	*3,788.5*	*3,654.7*
(Orion)	*(1,266.2)*	*(1,245.7)*	*(1,146.7)*	*(1,119.3)*	*(1,000.0)*
(SLS)	*(1,775.4)*	*(1,837.5)*	*(1,933.0)*	*(2,221.2)*	*(2,253.3)*
(Expl Grnd Sys)	*(400.1)*	*(357.8)*	*(388.7)*	*(448.1)*	*(401.3)*
Exploration R&D	*1,580.0*	*1,854.5*	*2,013.0*	*2,850.4*	*3,387.6*
(Adv Expl Systems)	*(255.6)*	*(239.8)*	*(188.3)*	*(146.7)*	*(130.1)*
(Cislunar/Surf Capblty)	*(363.0)*	*(647.0)*	*(967.7)*	*(1,775.9)*	*(2,360.0)*
(Gateway)	*(821.4)*	*(827.7)*	*(717.0)*	*(787.8)*	*(757.5)*
(Human Research Prog)	*(140.0)*	*(140.0)*	*(140.0)*	*(140.0)*	*(140.0)*
Exploration Technology	**1,014.3**	**976.1**	**995.4**	**964.4**	**943.1**
LEO & Spcflt Ops	**4,285.7**	**4,369.5**	**4,369.5**	**4,235.5**	**4,182.3**
ISS	*1,458.2*	*1,448.5*	*1,449.4*	*1,352.6*	*1,315.7*
Space Trans (for ISS)	*1,828.6*	*1,854.1*	*1,814.5*	*1,746.2*	*1,727.2*
Space & Flt Spprt	*848.9*	*891.9*	*905.7*	*911.8*	*914.5*
Cmrcl LEO Developmnt	*150.0*	*175.0*	*200.0*	*225.0*	*22.50*
Science	**6,303.7**	**6,319.0**	**6,319.0**	**5,846.5**	**5,815.0**
Earth Science	*1,779.8*	*1,785.6*	*1,779.7*	*1,666.5*	*1,674.6*
Planetary	*2,622.1*	*2,577.3*	*2,629.4*	*2,402.4*	*2,350.9*
Astrophysics	*844.8*	*902.4*	*965.2*	*913.5*	*907.7*
JWST	*352.6*	*415.1*	*175.4*	*172.0*	*172.0*
Heliophysics	*704.5*	*638.6*	*769.3*	*692.0*	*709.8*
Aeronautics	**666.9**	**673.6**	**680.3**	**587.1**	**587.0**
STEM Engagement	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Safety, Security, MS	**3,084.6**	**3,084.6**	**3,084.6**	**2,871.6**	**2,871.6**
CECR	**600.4**	**468.8**	**468.8**	**468.8**	**387.8**
Inspector General	**41.7**	**42.1**	**42.5**	**42.5**	**43.0**
TOTAL	**21,019.0**	**21,229.2**	**21,441.5**	**21,655.9**	**21,872.5**

Notes: Source: NASA FY2020 budget documentation, March 11, 2019. NASA says the total is 1 percent inflationary growth per year. Does not reflect any changes the Administration is planning to pay for the Artemis program. Columns may not add due to rounding. Text and numbers in *italics* are subtotals. Text and numbers in (*italics in parentheses*) are sub-subtotals. N/A = not applicable. CECR = Construction and Environmental Compliance and Restoration.