1. **(4 pts). Why Should America invest in Science Research?**
   a. Starting with an historical perspective from Vannevar Bush's seminal 1944 paper on *Science: The Endless Frontier* and using modern arguments presented in class and in the *Beyond Sputnik* textbook, write a cogent paragraph on why you believe America should invest in scientific research.

      Investment in space science will pay dividends in both the long- and short-term future of American economics and public well-being. Although academic research may not seem to produce tangible benefits to the country, as Vannevar Bush writes in his essay Science: The Endless Frontier, "further progress of industrial development would eventually stagnate if basic scientific research were long neglected." More recently, since WWII, "scientific advances have been central to U.S. military and economic preeminence" (Beyond Sputnik pg 72). Advances in space science and rocketry, especially, may have implications for the U.S. military and national defense, subjects of great interest to the federal government.

   b. Now, let's turn to space science specifically. What arguments would you put forward to taxpayers to invest $25 billion/yr in NASA? What is the return on investment from telescopes like Hubble and Webb, sample return missions from Mars, and observations of the Sun?

      Although missions like Hubble and Webb may require significant funds to build, they provide innumerable scientific insights that would not otherwise be possible and inspire curiosity in the general public. The first JWST image to be publicly released generated over 120,000 retweets on the @NASAWebb account, spawned articles in nearly every major news outlet, and was otherwise shared innumerable times around the globe. Clearly there is a huge interest from the public in scientific advancements of this kind. These types of large scientific missions also lead to more tangible scientific results that are relevant to life on Earth. The Parker Solar Probe, for example, is another costly NASA mission, but is facilitating advancements in our understanding of space weather events such as coronal mass ejections, which can trigger significant events on Earth such as power outages. A better understanding of the physics behind these events will lead to a better ability to forecast them and mitigate their effects.

2. **(6 pts). The *Outer Space Treaty* of 1967 and the *Artemis Accords*.**
   a. The *Outer Space Treaty* was the first multilateral agreement in international space law. It has been signed by 111 countries to date. After doing some research online on this Treaty, discuss the elements that make it the gold standard for any future international agreements for space exploration.

      The Outer Space Treaty forms a basis for international cooperation in space. It places limits on the use of space for military purposes, including barring nuclear weapons in space and ensuring that the Moon and other planetary bodies are used for only peaceful purposes. It also forbids governments from declaring sovereignty over any portion of outer space. Treaty (in principle) ensures that the exploration of space remains a peaceful endeavor.

b. In your view, what is missing from the 1967 Treaty considering the way that space exploration will be conducted in this decade and beyond?

One significant area in which the Outer Space Treaty remains ambiguous is regarding resource extraction, such as mining on the Moon or asteroids. With rapidly increasing interest in in-situ resource utilization (ISRU) by NASA as well as private space companies, the treaty provides little guidance or clarity as to how (or whether) this burgeoning industry should be regulated.

c. Recently, NASA and the U.S. State Department drafted a new framework for cooperation in space, including the Moon and Mars, called the *Artemis Accords.* Twenty nations have signed on so far, although Russia and China are notably absent. After doing some research online, discuss the major tenants of the *Artemis Accords.* How does it fill the gaps of the *Outer Space Treaty* and what issues remain to be addressed?

While affirming that space exploration should be a peaceful endeavor, the *Artemis Accords* also emphasize cooperation between nations including the development of common infrastructure, open access to scientific data, and the preservation of space heritage sites. The *Artemis Accords* provide more specific guidance on how space exploration should be conducted in the modern age. As noted above, the Outer Space Treaty is at best vague regarding the utilization of space resources. The *Artemis Accords* seek to amend this by stating that "the extraction of space resources does not inherently constitute national appropriation under Article II of the *Outer Space Treaty*." The accords also address issues stemming from the increased use of space including orbital debris, and "safety zones" around spacecraft and infrastructure. These issues will only become more prevalent as more countries as well as private entities seek to operate in space.

What is perhaps missing from the *Artemis Accords* is any reference to countries or entities that could be considered "hostile" actors. The accords are quite American centric, with only 21 countries having signed on. China and Russia are notably absent. The accords lack provisions for resolving conflicts that may arise with these countries. Rather than attempting to reach out to China and Russia, the accords rely almost entirely on willful cooperation and communication between countries that already have generally amicable diplomatic relations.

3. **(2 pts).** In President Eisenhower's 1961 Farewell Address, he talked about guarding "against the acquisition of unwarranted influence … by the military-industrial complex". He also warned against the nation becoming a "captive of the scientific-technological elite". Do you think Eisenhower's warning still has relevance today? Discuss why or why not.

Coined by Eisenhower, the military-industrial complex refers to the relationship between the military and the defense industry, which manufactures weapons and other supplies. In his speech, Eisenhower expressed concern that this close relationship would place too much power in the hands of the defense industry, which is accountable to shareholders, rather than the government, which is accountable to voters. With most arms manufacturing performed by a small number of large companies, massive power is consolidated by what Eisenhower refers to as the "scientific-technological elite." Rather than acting in the best interest of the American people, Eisenhower was concerned that these elite would use their power for their own personal interest.

Eisenhower's warning about the power of these elite still rings true today. Even more so than in 1961, a large portion of wealth is concentrated in the hands of a few. Since Eisenhower's time, the Supreme Court ruled in the controversial Citizens United v. Federal

Election Commission case that corporations (and by association their leaders) can spend an unlimited amount of money to influence elections and politics. Thus, it is even more important today for the public to be aware of the outsized influence and power of a few "elite" people.

4. **(4 pts).** Konstantin Tsiolkovsky is often considered the father of Soviet/Russian human space flight and Robert Goddard is similarly considered as the pioneer of the American space program. Summarize each of their accomplishments as well as compare and contrast their contributions to human space flight. Include in your analysis discussion of their contributions to:
   - The basics of rocketry and rocket propulsion.
   - Theory vs. the practice (launches, fuels, etc.) of rocketry.

   Tsiolkovsky is perhaps most known for deriving the rocket equation, which establishes a relationship between the change in the rocket's speed and the exhaust velocity of the fuel and the initial and final mass of the rocket. The equation is fundamental for the field of aerospace engineering. One implication of the rocket equation is that in order to achieve the velocities necessary to launch a rocket to space, a very large portion of the mass budget must be dedicated to fuel. Tsiolkovsky also made important realizations about living in outer space. When entering or exiting a spacecraft, he noted the need for air locks to ensure that the air inside of the craft is not lost to the vacuum of space. Airlocks, consisting of two sealed doors, which are never opened simultaneously, are essential for astronauts on the International Space Station to perform space walks. He also proposed the possibility of building a space station in Earth orbit, including the possibility of rotating the spacecraft to simulate gravity.

   Goddard's achievements were primarily experimental rather than theoretical. Perhaps Goddard's most important achievement was the launch of the first liquid-fueled rocket. Goddard's work in propulsion set the stage for future rockets to be able to reach space and proved that the physics behind Tsiolkovsky's rocket equation held true.

   The achievements of both men are similar in that they were visionaries, working on the cutting edge of what was generally considered possible. Both were heavily critiqued by their contemporaries before ultimately being proven to be correct. The biggest difference between the two is their fields of study, with Tsiolkovsky being limited to purely theoretical work, while Goddard applied the theory or rocketry and propulsion to perform actual experiments with real rockets.

5. **(6 pts).** ***The Apollo Program***

   a. Discuss why the Apollo program achieved Kennedy's aim of placing astronauts on the Moon in 1969 despite the lack of relevant technologies when Kennedy set the goal in 1961.

      The main reason that the Apollo program was successful in landing astronauts on the surface of the Moon before the USSR was the immense financial investment in the space program by the U.S. Federal government. The perceived threat of Soviet technological dominance bolstered by the successes of Sputnik, Gagarin, etc. provided the motivation for funding the R&D needed to achieve the goal of setting foot on the moon.

   b. What were the successes and failures of the Apollo program?

      Successes: Landed humans on the Moon, definitively defeated Russians in Space race, saved lives of Apollo 13 astronauts, invented Systems Engineering; developed giant impact model for formation of the Moon; began international partnerships.

      Failures: Apollo 1 deaths, relatively few technology spin-offs, quickly became boring TV for American public, systems engineering did not translate to solving other social programs, did not create a sustained American space program.

c. In your opinion, why is it ***unlikely*** that NASA will undertake another space exploration program of the magnitude (cost) of Apollo? Even with the Artemis goal of a human mission to the Moon by the middle of the decade, this government-funded program will likely be very different from the Apollo missions. What is different today?

This kind of major project is only taken on by governments in the face of a national/political challenge or crisis. Without the Russians as an enemy to defeat, the Americans would never have challenged themselves to go to the Moon in the first place. This was a unique time and unique circumstances that came together to invest heavily in the space program. Although the Artemis program plans to return humans to the Moon, the total investment by the federal government will almost certainly be a much smaller fraction of the total budget (currently estimated to be <10% of Apollo for first 3 Artemis missions). Today, the American public and Congress are simply not willing to spend on space as much as was spent during Apollo given the relative lack of urgency compared to the 1960s.

6. **(6 pts**). The early Earth-Moon system after formation 4.5 billion years ago looked quite different than today. The Earth's rotation period was only 5 hours, and the Moon was only 3.5 Earth radii away from Earth versus the 24 hour Earth rotation period and 60 Earth radii distance of the Moon from Earth today.

a. How and why did this dramatic change occur? What are the physical principles at work here?

This change is caused by the gravitational force between the Earth and the Moon and an exchange of energy between the two bodies. The tidal force of the Moon's gravity forms a bulge in the Earth's Oceans under where the Moon is orbiting the Earth. However, Earth's rotation causes this bulge to be positioned slightly ahead of the Moon. The relative position of the bulge and the Moon facilitates a transfer of energy to the Moon, which over time causes the Earth's rotation to slow and the Moon to orbit the Earth at a larger radius.

b. What are the arguments in favor of the Moon's creation via the impact of the proto-Earth with a large asteroid?

One piece of evidence pointing to the giant impact hypothesis is that the Moon is less dense than the Earth, which could be caused by an impactor breaking off the crust of the Earth rather than the core, which is much denser. The Moon also orbits the Earth in a plane very similar to the ecliptic plane. If the Moon formed from the remnants of a collision, the material would tend to gather near the ecliptic plane. Finally, the isotopic ratios of terrestrial and lunar material are very similar, suggesting that the material has a common origin.

c. In Dr. Bottke's lecture, he emphasized why the Moon is crucial to understand the bombardment history of both the Earth and the Moon. What else does this impact history tell us about the evolution of the solar system and a possible rearrangement of the planets?

In the early solar system, the rate of impacts for planetary bodies, including the Moon, was much higher than it is today. Observations of the oldest impact basins suggest that there were many more impacts during these early times than current models can account for. Simulations and modeling of planetary accretion do not produce enough leftover material after planetary accretion to account for the number of impacts that we observe. A possible resolution to this discrepancy is that a migration of the giant planets produced an instability in cometesimals in the outer solar system, flinging them inwards towards the sun, where they impacted the inner planetary bodies. If this scenario is correct, it means that the planets of our solar system formed in much different orbits than we currently observe them.