Undergraduate Thesis Prospectus

High-resolution imaging of atmospheric nitrogen dioxide

(technical research project in Mechanical and Aerospace Engineering)

Discovery and Triumph: Promoting Space Exploration by Appealing to Values

(STS research project)

by

Sami Khatouri

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technical project collaborators:
MAE 4690/4700 Spacecraft Design I/II

On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

signed: _____ date: _____

approved: _____ date: _____
Peter Norton, Department of Engineering and Society

approved: _____ date: _____
Christopher P. Goyne, Department of Mechanical and Aerospace Engineering

General research problem

How can space technology benefit society?

Since Sputnik was launched in 1957 (Kuznetsov, et al., 2015), humans have launched over 8,000 space objects. Several have explored the Solar System and beyond (Garber & Launius). Spaceflight is expensive, but space-based Earth observation is vital to weather prediction, atmospheric monitoring, and other purposes (NASA, 2015). Satellites support communication and navigation (Stromberg, 2012). Space-based scientific research and development has contributed to many fields, including medicine, transportation, and public safety (Coleman, 2012).

High-resolution imaging of atmospheric nitrogen dioxide

How can atmospheric nitrogen dioxide data in cities be precisely imaged?

This is a team capstone project in the Department of Mechanical and Aerospace Engineering. The students enrolled in MAE 4690/4700: Spacecraft Design I/II, advised by Dr. Chris Goyne, will develop a 3U CubeSat, a type of small satellite, that can image atmospheric nitrogen dioxide levels of chosen cities with high spatial resolution.

Over 95% of the global population lives in areas with air pollution exceeding designated health standards (Health Effects Institute, 2018). Pollutant distributions have shown substantial intra-urban variability causing differences in health and life expectancy (Jerrett, et al., 2005). NO_2, a byproduct of combustion-related emissions, is a strong indicator of anthropogenic pollution and is linked to adverse health effects, including cardiovascular and respiratory problems (Brook, et al., 2007). Imagery of NO_2 levels over a city can provide knowledge about pollution sources and inform policymaking to protect public health. However, NO_2 is a

chemically reactive gas, causing high spatial and temporal variability, and imagery from current satellite sensors are of too low spatial resolution to be useful for local decision-making (Choi, et al. 2014). Therefore, high-resolution NO_2 imagery would allow for clearer links to pollution sources and better-informed policy.

The primary objective of this project is to develop and use a high-resolution NO_2 sensing satellite to collect spatial data for four major cities using a spectrograph developed by the U.Va. Department of Astronomy. To improve on existing data, NO_2 distributions are to be imaged with a spatial resolution of around 200m x 800m, requiring a spacecraft in Low Earth Orbit (LEO) (Pusede, et al., 2018). The spacecraft must conform to the 3U CubeSat form factor with 1.5U allocated for the spectrograph payload. It must meet the design and testing requirements given by NASA's CubeSat Design Specifications to be eligible for launch (The CubeSat Program, 2014).

Space-based remote sensing of NO_2 tropospheric columns from GOME (1996-2003), SCIAMACHY (2002-2011), OMI (2004-), GOME-2 (2007-), and OMPS (2011-) have contributed substantially to our understanding of regional and global NO_2 variability and urban surface air quality (Richter, 2011). TEMPO (Tropospheric Emissions: Monitoring of Pollution), a mission currently in development, will image NO_2 columns over North America with a resolution of 8km x 4.5km (Chance, 2017). However, while satellite data can provide spatially continuous NO_2 column maps across inter-annual periods, the current generation of sensors lack the spatial resolution required to capture the fine-scale variability (<1 km^2) relevant to fully characterizing intra-urban NO_2 distributions.

Development of the CubeSat will be divided into the following component teams: Program Management; Communications; Software and Avionics; Power, Thermal, and Environment; Attitude Determination and Control System (ADACS) and Orbits; and Structures

and Integration. A Conceptual Design Review has been completed, and Preliminary and Critical Design Reviews will be completed as development proceeds, after which assembly of the CubeSat bus will begin. Testing will be conducted on the completed spacecraft bus according to the CubeSat Design Specifications, including vibration/shock testing and thermal vacuum bakeout testing. Following a Mission Readiness Review, the CubeSat will be delivered to the launch provider for launch and deployment. The spacecraft will orbit and operate for at least one year after deployment.

In the event of a successful mission, the CubeSat will provide the most informative intra-urban NO_2 measurements to date, with higher spatial resolution than other missions of similar scope and over a greater timespan than is possible via aircraft or weather balloons. Findings from this research may prove very useful to policymakers in minimizing pollution sources.

Discovery and Triumph: Promoting Space Exploration by Appealing to Values

How do space organizations appeal to values to promote space exploration?

Most public and private space organizations rely on public approval, so they engage in public relations campaigns to promote their space ventures. Funding for public agencies, such as NASA, depends on public opinion (Steinberg, 2011). NASA's public relations budget for fiscal year 2018 was $54.9 million (NASA, 2019). Private space exploration companies now compete (Yuhas, 2018), and public approval of a company attracts talent and prestige. These groups therefore invoke values, including a supposedly innate human yearning for discovery and understanding, national prestige and exceptionalism, and the alleged interplanetary destiny of humanity (Launius, 2017).

Billings (2007), in her examination of the history of spaceflight advocacy, writes that its rhetoric "has sustained an ideology of American exceptionalism and reinforced long-standing beliefs in progress, growth, and capitalist democracy" and "has tended to rest on the assumption that the values of 'believers' are (or should be) shared by others as well." Slobodian (2015) discusses narratives of space colonization, finding promoters invoke "biological drives, species survival, inclusiveness and utopian ideals."

Bain et al. (2006) find that values considered central to human nature are viewed as more important, and that "human nature beliefs" predict reactions to "value-laden rhetorical statements." Some values that are invoked to promote spaceflight implicate human nature.

Steinberg (2011) explores the responsiveness of American space policy to public opinion, finding that "the public supports the idea of space exploration, while also feeling that spending on space exploration is 'too high'" and that spaceflight spending varies directly with public tolerance for it. However, a 1997 poll showed that the average estimate of NASA's share of the federal budget was 20%, compared to the actual budget of less than 1% (Launius, 2003). Cobb (2011) finds that "those who support space activities tend to be younger, male, Republican, and have a higher level of education and socioeconomic status."

Public space agencies aim to advance the aerospace capabilities and prestige of their respective countries, though they also claim to seek the advancement of scientific knowledge. NASA's stated vision is "to discover and expand knowledge for the benefit of humanity" (Loff, 2015). Private for-profit space companies often invoke nobler objectives. SpaceX claims its "ultimate goal" is "enabling people to live on other planets" (SpaceX, 2012). Aerospace contractors depend on public agencies like NASA. Jacobs Engineering Group states that they "share the commitment to advocate NASA's deep space exploration program and endorse its

vision to pursue the benefits returned to our country from long-term national investment in space exploration and scientific discovery" (Business Wire, 2018). The Planetary Society is the largest of many nonprofits that promote space exploration, engaging in political advocacy, public outreach, and research. Planetary Society CEO Bill Nye claims its goal is to "advance space science and exploration for the betterment of humankind." According to Nye: "We want everyone everywhere to understand our cosmos and, importantly, our place within it" (Planetary Society, 2014).

The general public is divided on government spending on space exploration. Critics of space expenditures contend it diverts funds from more important needs. Professor Amitai Etzioni writes: "What is needed are major technological breakthroughs that will allow for protecting earth while sustaining a healthy level of economic activity... Hence, any serious Mars endeavor will inevitably cut into the drive to save Mother Earth" (Etzioni, 2018). Proponents of space exploration allege numerous social benefits, often invoking value-laden rhetoric similar to that of organized advocates. Species survival is an important example. James Orsulak, in his blog post, writes: "Space exploration is one of the most important endeavors our civilization will undertake. … This is one movement that cannot end. It is the only way to ensure the continuation of our species" (Orsulak, 2014).

References

Bain, P. G., Kashima, Y., & Haslam, N. (2006). Conceptual beliefs about human values and their implications: Human nature beliefs predict value importance, value trade-offs, and responses to value-laden rhetoric. *Journal of Personality and Social Psychology, 91*(2), 351–367. doi: 10.1037/0022-3514.91.2.351

Billings, Linda. 2007. "Overview: Ideology, Advocacy, and Spaceflight—Evolution of a Cultural Narrative." Pp. 483–99 in Steven J. Dick and Roger D. Launius, eds., *The Societal Impact of Spaceflight.* Washington, DC: NASA.

Brook, J. R., Burnett, R. T., Dann, T. F., Cakmak, S., Goldberg, M. S., Fan, X., & Wheeler, A. J. (2007). Further interpretation of the acute effect of nitrogen dioxide observed in Canadian time-series studies. *Journal of Exposure Science & Environmental Epidemiology, 17*(S2). doi: 10.1038/sj.jes.7500626

Business Wire. (2018, April 17). Jacobs Joins Coalition for Deep Space Exploration [Press release]. https://www.businesswire.com/news/home/20160315005644/en/

Chance, K. (2017). North American pollution measurements from geostationary orbit with Tropospheric Emissions: Monitoring of Pollution (TEMPO). *Light, Energy and the Environment*. doi: 10.1364/pv.2017.jtu2a.2

Choi, S., Joiner, J., Choi, Y., Duncan, B. N., & Bucsela, E. (2014, January 6). Global free tropospheric NO2 abundances derived using a cloud slicing technique applied to satellite observations from the aura ozone monitoring instrument (OMI). https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20140009174.pdf

Cobb, W. N. W. (2011). Who's supporting space activities? An 'issue public' for US space policy. *Space Policy, 27(4),* 234–239. doi: 10.1016/j.spacepol.2011.09.007

Coleman, D., & Reiny, S. (2012). Spinoff 2012

CubeSat Program (2014). CubeSat Design Specification Rev. 13. [online] California Polytechnic State University. http://cubesat.org.www.cubesat.org/images/developers/cds_rev13_final2.pdf

Etzioni, A., & Etzioni, E. (2018, Aug 25). https://nationalinterest.org/blog/buzz/humanity-would-be-better-saving-earth-rather-colonizing-mars-29712

Garber, S., & Launius, R. (n.d.). A Brief History of NASA. https://history.nasa.gov/factsheet.htm.

Health Effects Institute. (2018, April 17). Over 7 Billion People Face Unsafe Air: State of Global Air 2018 [Press release]. https://www.healtheffects.org/sites/default/files/soga2018-press-release_0.pdf

Jerrett, M., Burnett, R. T., Ma, R., Pope, C. A., Krewski, D., Newbold, K. B., … Thun, M. J. (2005). Spatial Analysis of Air Pollution and Mortality in Los Angeles. *Epidemiology*, *16*(6), 727–736.

Kuznetsov, V., Sinelnikov, V., & Alpert, S. (2015). Yakov Alpert: Sputnik-1 and the first satellite ionospheric experiment. *Advances in Space Research*, *55*(12), 2833–2839. doi: 10.1016/j.asr.2015.02.033

Launius, R. D. (2003). Public opinion polls and perceptions of US human spaceflight. *Space Policy*, *19*(3), 163–175. doi: 10.1016/s0265-9646(03)00039-0

Launius, R. D. (2017). NASAs Quest for Human Spaceflight Popular Appeal*. *Social Science Quarterly*, *98*(4), 1216–1232. doi: 10.1111/ssqu.12473

Loff, S. (2015, Jan 28). About NASA. https://www.nasa.gov/about/index.html

NASA. (2015, April 20). TIROS, the Nation's First Weather Satellite. https://www.nasa.gov/multimedia/imagegallery/image_feature_1627.html.

NASA. (2019). FY 2020 Budget Request, FY 2020 Budget RequestSD31 (n.d.). nasa.gov/sites/default/files/atoms/files/fy_2020_congressional_justification.pdf

Orsulak, J. (2014, November 4). The Importance of Space Exploration: Why We Must Press On. http://www.fuelspace.org/blog/2014/11/4/the-importance-of-human-space-travel.

Planetary Society. (2014, March 17). "The Planetary Society Announces Its Largest Single Donor Gift." The Planetary Society Blog. http://www.planetary.org/press-room/releases/2014/largest-single-donor-gift.html.

Pusede, S., Skrutskie, M., and Goyne, C. (2018). "High-resolution atmospheric nitrogen dioxide (NO2) observations using a CubeSat in LEO," University of Virginia, National Science Foundation Proposal.

Richter, A., Begoin, M., Hilboll, A., & Burrows, J. P. (2011). An improved NO2 retrieval for the GOME-2 satellite instrument. *Atmospheric Measurement Techniques*, *4*(6), 1147–1159. doi: 10.5194/amt-4-1147-2011

Slobodian, R. E. (2015). Selling space colonization and immortality: A psychosocial, anthropological critique of the rush to colonize Mars. *Acta Astronautica*, *113*, 89–104. doi: 10.1016/j.actaastro.2015.03.027

SpaceX. (2012, Nov 28). https://www.spacex.com/about

Steinberg, Alan. (2011). Space policy responsiveness: The relationship between public opinion and NASA funding. *Space Policy. 27.* 10.1016/j.spacepol.2011.07.003.

Stromberg, J. (2012, July 10). Fifty Years Ago Today, the First Communications Satellite Was Launched Into Space. Retrieved from https://www.smithsonianmag.com/smithsonian-institution/fifty-years-ago-today-the-first-communications-satellite-was-launched-into-space-1454520/.

Yuhas, A. (2018, February 9). The new space race: how billionaires launched the next era of exploration. The Guardian. https://www.theguardian.com/science/2018/feb/09/new-space-race-billionaires-elon-musk-jeff-bezos.