Uni-Flower: A Novel Proposal for University-Built Nanosatellites in Flower Constellation

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Abstract

The purpose of this paper is to introduce some Flower Constellation applications and to begin an open dialogue on the Uni-Flower proposal: the first University-Built Nanosatellites in Flower Constellation. The basic outline for a novel research project is proposed which makes use of micro- or nanosatellites-built solely by universities-in a Flower Constellation orbit, which is determined by the mission of the satellites. Specific scenarios are described in detail, with options left open for input, feedback, and completely new and different mission ideas. The two projects described include constellations orbiting the Earth for atmospheric science data collection and constellations for measurement of the magnetic field dynamics. A final mission-based section describes advanced Flower Constellations for which a scientific application has not been found. For the Uni-Flower concept, possible scientific objectives, orbit design, some details of satellite design, educational possibilities, and university interaction and collaboration prospects (as well as multi-disciplinary aspects) are thoroughly discussed. One should quickly realize that any such research project would be a massive undertaking—especially from the administrative, funding, and time requirement standpoints—so preliminary concepts on the management of such a research project are also presented.

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1 Introduction

In recent years, micro- and nanosatellites have been researched and built by universities, government agencies, and corporations for highly specific, low-cost missions. With the price of putting something into Earth orbit hovering around $10,000 per pound, nanosatellites (generally weighing less than 20 pounds) have the advantage of low-budget access to space for a specific scientific mission or demonstration of technology. The disadvantages of nanosatellites are the necessity to piggyback during launch and the lower degree of robustness due to their specific nature. There have been many discussions and attempts to insert nanosatellites into traditional constellations, but to date, a Flower Constellation (FC) has never been attempted using any type of satellite, although it has been shown considerable interest.

Since Flower Constellations can be designed with large numbers of cooperating and/or complimentary satellites, it is logical to consider nanosatellites to reduce the cost, while at the same time offering the possibility of broadly distributing both the effort and the cost by utilizing a university consortium (it is possible that the space grant universities would join such a consortium along with other universities interested in the project). Involving many universities in such a consortium would provide a means to harness the energy, enthusiasm and innovation of the next generation of spacecraft engineers.

Flower Constellations have been introduced in theory by Mortari et. al. [1] and further insights can be found in Wilkins [2]. Some other general ideas can be found in references [3, 4, 5] while the first application appears in references [6, 7] for a GPS-like Global Navigation FC system. Recently, the FC theory has been extended to include dual-compatible and multi-compatible orbits, by the introduction of the “Synodic” and the “Relative” FCs [8]. A doubly-repeating ground track FC (Ω not zero due to $J_2$) will be used to demonstrate the utility of FCs for the dynamic magnetic field measurement project.

The Uni-Flower concept would bring together universities, industry, and government to build a Flower Constellation of micro- or nanosatellites for a specific scientific application. This partnership would serve to further scientific knowledge as well as to educate the next generation of spacecraft engineers.

2 Preliminary Uni-Flower Applications

The idea behind the Uni-Flower concept is to bring together universities and corporations to build a Flower Constellation of micro- or nanosatellites for a specific scientific application. Many interesting and useful FCs have been discovered with several more being discovered each day by Mortari and his research group. The potential application of these FCs is unlimited in that they could be used for a constellation around
Mars or an asteroid as well as for Earth observation. Possible functions of university-built satellites that would useful from a scientific or engineering standpoint include but are not limited to:

1. ocean altimeter measurements as a tsunami prediction and warning system
   (a) high-precision altimeter measurements of ocean waves
   (b) observing and tracking fast-moving wavefronts
   (c) communication between satellites and ground
   (d) onboard verification and reconciling of Earthquake data

2. laser ranging for changes in topography including
   (a) shoreline erosion
   (b) changes in volcano elevation and shape for eruption prediction
   (c) size and changes in polar ice caps
   (d) changes in ocean height level

3. a new GPS constellation with fewer satellites and the same coverage parameters

4. wind measurements and spectroscopy of the atmosphere for
   (a) refining the model of the atmosphere
   (b) weather and hazardous condition predictions
   (c) measurements and changes of ozone levels

5. high-resolution imaging applications such as
   (a) ecological changes (climate, forest size, etc.)
   (b) sociological studies such as urban size and planning

6. magnetic and electric field measurements
   (a) a complete map of the magnetic or electric field around Earth
   (b) plasma studies
   (c) dynamic solar interaction

7. prototype communications between satellites and Earth or between satellites

8. a novel low-power ground penetrating radar used only in specified regions of interest for
   (a) geological structure studies over areas of interest
   (b) fault line studies for Earthquake prediction
(c) military applications such as subterranean bunkers

9. space debris identification, observation, and tracking

10. solar activity measurements and prediction of effects

11. orbit parameter measurements and refinement
   (a) J2 perturbation measurement
   (b) gravity model refinement

12. technology demonstration for previously academic equipment such as
   (a) star trackers and algorithms
   (b) propulsion systems
   (c) tethered spacecraft
   (d) solar sails
   (e) formation flying concepts
   (f) rendezvous and docking procedures
   (g) GPS-based orbital absolute position
   (h) GPS-based and line-of-sight measurement of relative position between two spacecraft
   (i) attitude control algorithms and hardware
   (j) obtaining flight rating for electronics
   (k) autonomous operations and navigation

Obviously, countless more orbits and scientific applications exist—including for bodies other than the Earth. The authors included the above list just to give an initial taste of ideas that have already received thought, but have chosen to elaborate on two possible missions. The authors also wish to take a moment to encourage an open dialogue concerning the future of the Uni-Flower proposal.

3 Examples of Uni-Flower Mission Concepts

The two Uni-Flower missions that this paper details follow. First, a mission that makes use of a constellation of nanosatellites in a sun-synchronous string of pearls configuration for Earth atmospheric data collection is described. Second, a mission that allows the power of one particular FC to be demonstrated for measuring the dynamics of the Earth’s magnetic field is detailed. Finally, advanced Flower Constellation designs are presented for which a scientific application has yet to be found.
### 3.1 Passive Earth Atmospheric Observation

One idea for a Uni-Flower constellation uses passive signals to measure the index of refraction at a point in the Earth’s atmosphere (it should be noted that this idea can be generalized to work for any planet with a sufficient atmosphere). From the index of refraction data, atmospheric scientists can back out a model of the atmosphere, determine amounts of trace gases, and measure water vapor content above a point on the Earth. The passive signal measurements are taken by one satellite at a time via sunlight (with only a receiver as the necessary instrument). Therefore, a particularly aligned sun-synchronous orbit where the sun will be seen rising and setting through the Earth’s atmosphere (near eclipse) is required.

Sun-synchronous orbits are those with a fixed orbit plane orientation with respect to the Earth-Sun line. Thus, the orbit plane maintains the same orientation with respect to the Sun, and the satellite crosses the equator at the same local time each day. In order to get a sun-synchronous orbit, the rate of change of $\Omega$ that is proportional to the difference between a sidereal day (the time spent between two successive crossings of a star to the local meridian) and a sun day (time spent by two successive crossings of the sun to the local meridian) must be obtained using the $J_2$ perturbation. The effect due to the $J_2$ perturbation is the second order gravitational perturbation in a satellite’s orbit due to the fact that the Earth is oblate and not a perfect sphere. The Earth-Sun line rotates with angular velocity equal to the Earth’s mean motion

$$\frac{360}{365.25} \simeq -1 \text{ deg/day}$$

while the $J_2$ effect causes a precession of the node line

$$\dot{\Omega} = -\frac{3}{2} J_2 \left[ \frac{R_E}{a(1 - e^2)} \right]^2 n \cos i$$

Setting this velocity equal to the Earth’s mean motion, we obtain an equation that establishes the sun-synchronicity

$$\cos i = -1.227 \cdot 10^{-4} \sqrt{\frac{a^3}{\mu}} \left[ \frac{a(1 - e^2)}{R_E} \right]^2$$

For circular orbits this expression becomes

$$\cos i = -1.227 \cdot 10^{-4} \frac{a^{7/2}}{R_E \sqrt{\mu}} = 1.7311 \cdot 10^{-9} a^{7/2}$$

The proposed constellation for this scientific purpose is a string of pearls configuration in an eccentric sun-synchronous orbit. This orbit has a prescribed inclination in order to be sun-synchronous. Flower Constellations have two prescribed parameters that
determine the orbit, the number of petals, $N_p$, and the number days, $N_d$. According to the Flower Constellation theory [1], we have

$$N_p T = N_p \cdot 2\pi \sqrt{\frac{a^3}{\mu}} = N_d \frac{2\pi}{\omega_E} \tag{5}$$

and thus we can solve for the semi-major axis and obtain

$$a = \sqrt[3]{\frac{\mu (N_d N_p \omega_E)}{2}} \tag{6}$$

Since we do not want rotation of the apsidal line ($\dot{\omega} = 0$), we are free to select one of the critical inclination values, $i = 63.4^\circ$ or $i = 116.6^\circ$. Since the constellation uses sun-synchronous orbits, the orbit must be retrograde, and the inclination selection of $i = 116.6^\circ$ becomes mandatory. With this value of the orbit inclination, Eq. (3) becomes a relationship between eccentricity, $e$, and semi-major axis, $a$. This relationship, which is plotted in Figs. 1 and 2, allows us to evaluate the orbit eccentricity and the perigee altitude for assigned values of $N_p$ and $N_d$.

Another option is to use active measurements between spacecraft in the same orbit\textsuperscript{8}. For active measurements, a uniform distribution of satellites in a circular orbit is the simplest case. Geometry dictates the altitude of the spacecraft in the circular orbit such that the satellites can see each other through the atmosphere. Figure 3 shows a simple distribution. This concept could be easily extend to 3D objects (regular polyhedra). However, the 3D objects require more satellites and therefore are more expensive.

\textsuperscript{8}It should be noted that there also exists a solution which combines active and passive measurements.

\begin{figure}[h]
\centering
\begin{subfigure}{0.4\textwidth}
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\includegraphics[width=\textwidth]{figure1.png}
\caption{$e = e(a)$}
\end{subfigure}
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\begin{subfigure}{0.4\textwidth}
\centering
\includegraphics[width=\textwidth]{figure2.png}
\caption{$h_p = h_p(a)$}
\end{subfigure}
\end{figure}
This scientific mission, while still a preliminary idea for Earth atmospheric sciences, involves a small constellation of satellites that are placed on the same sun-synchronous orbit. This orbit has an operating orbital range in which the Sun is seen setting and/or rising through the atmosphere. This allows the index of refraction measurement from a passive source at varying altitudes in the atmosphere. If the satellites are put into an elliptical orbit, then the altitudes measured in the atmosphere will vary. The rotation of the Earth will effect the orbit such that varying latitudes are measured also. In this way, the entire Earth can be measured.

Figure 3: Simple satellite distributions in circular orbit for atmospheric observation

3.2 Measuring the Dynamics of Earth’s Magnetic Field

The Flower Constellation theory uses a simple 2-body model that takes into account the two main linear $J_2$ effects. These are the rotation of the apsidal line

$$\dot{\varpi} = \frac{3}{4} J_2 \left( \frac{R_{eq}}{p} \right)^2 n (5 \cos^2 i - 1)$$

and the orbit precession

$$\dot{\Omega} = -\frac{3}{2} J_2 \left( \frac{R_{eq}}{p} \right)^2 n \cos i$$

where $i$ is the orbit inclination, $p$ is the semilatus rectum, $n$ the orbit mean motion, $J_2 = 0.000108263$, and $R_{eq}$ is the Earth equatorial radius.

*The theory does NOT include the effects of drag, solar pressure, higher harmonic terms of the gravitational field, and third body gravitational influence.*
As long as all the spacecraft orbits of the constellation are identically inclined—this occurs when the Flower Constellation axis coincides with the Earth spin axis—then the two main linear $J_2$ effects given in Eqs. (7) and (8) are identical for all the satellites. In this specific case the semi-major axis does not change. Therefore, the orbit period does not change and consequently, all of the orbits remain compatible or resonant. The invariance of the orbit period guarantees continuous synchronization of the whole constellation. This means that while the dynamics of all of the spacecraft remain beautifully synchronized (on orbits that are continuously reoriented in space), the dynamics of the whole constellation will not be, in general, periodic.

![Figure 4: Repeated critical inclinations as a function of the $\xi$ parameter](image)

In order to obtain a periodic linear $J_2$ effect, the apsidal line rotation and the orbit precession must be synchronized. This implies

$$K_\omega T_\omega = K_\omega \frac{2\pi}{\dot{\omega}} = K_\Omega \frac{2\pi}{\dot{\Omega}} = K_\Omega T_\Omega$$

(9)

where $K_\omega$ and $K_\Omega$ are two independent integer parameters. Equation (9), which is the equivalent of the synchronization relationship of the compatible/resonant orbits, is too restrictive. In fact, since the relative trajectory is invariant with respect to an axial rotation of $\frac{k}{N_p} 2\pi$ angles, where $1 \leq k \leq N_p$, then Eq. (9) can be rewritten in the more general form

$$K_\omega \frac{2\pi}{\dot{\omega}} = K_\Omega \frac{2\pi}{\dot{\Omega}} \frac{k}{N_p}$$

(10)

Substituting the expressions of $\dot{\omega}$ and $\dot{\Omega}$ provided in Eq. (7) and (8) into Eq. (10), and introducing the rational parameter

$$\xi = \frac{K_\omega N_p}{K_\Omega k}$$

(11)
we obtain the solving relationship

\[ 5 \cos^2 i + 2 \xi \cos i - 1 = 0 \]  \hspace{1cm} (12)

whose solutions are plotted in Fig. 4. This figure shows that prograde solutions are feasible for \( \xi > -2 \), with a limit of \( i = 90^\circ \) for \( \xi \to \infty \), and retrograde solutions for \( \xi < 2 \), with a limit of \( i = 90^\circ \) for \( \xi \to -\infty \). Based on the above, we can design orbits (and constellations) called repeated-repeated, or repeated\(^2\), that are dual compatible/resonant. The theory of the repeated\(^2\) orbits can be applied to those missions whose purpose is to get access to most of the 3-D space around the Earth. It is possible to design an “optimal” repeated\(^2\) orbit that, within a predicted lifetime \( T_{lt} \), has spanned an assigned 3-D space in a regular fashion. The idea is to make identical the predicted lifetime and the repetitiveness of the repeated\(^2\) orbit

\[ T_{lt} = T_{rep} = K_\omega T_\omega = K_\Omega T_\Omega \]  \hspace{1cm} (13)

This relationship allows the design of periodic relative motion along Earth-fixed paths that, within the mission lifetime and in a regular fashion, scan the whole assigned space around the Earth. Flower Constellations made with repeated\(^2\) orbits constitute a family of FCs that rotate, deform, and then repeat periodically. This is done by physically spanning all of the space between the two surfaces produced by continuous rotations of the orbit due to \( \dot{\omega} \) and \( \dot{\Omega} \) effects of the Earth oblateness \( (J_2) \).

![Figure 5: Undeformed orbit](image)

![Figure 6: Deformation after 300 days](image)

As an example, let us consider the simplest case, \( N_p = 3 \) and \( N_d = 1 \), that corresponds to an approximative 8 hour orbits to design an orbit (or constellation) to measure the magnetic field of the Earth (or any other magnetic body). This constellation uses highly elliptical orbits and takes advantage of \( \dot{\Omega} \) and \( \dot{\omega} \) to scan all the space between two altitudes, producing a 3-D map of the Earth’s magnetic field.
In Figs. 5-10, the inertial elliptical orbits, with proper phasing in the orbits, result in the satellites executing (in a rotating Earth-fixed frame) a period orbit with three apogees. In the presence of Earth oblateness, the ideal orbits are precessed at roughly a constant rate. The figures that follow show the deformation and rotation of the orbit frame due to $J_2$ perturbations with the original orbit and the deformed orbit over a series of time steps. For a better understanding of how this orbit behaves, a movie is available at FC web site\(^\parallel\).

\(\parallel\)FC web site: http://flowerconstellations.tamu.edu/

Figure 7: Deformation after 600 days

Figure 8: Deformation after 1,020 days

Figure 9: Deformation after 1,543 days

Figure 10: Deformation after 2,084 days

The Flower Constellation presented here completely repeats with a period of roughly

\(^\parallel\)FC web site: http://flowerconstellations.tamu.edu/
11.4 years. The advantage of this FC is that over the course of the 11.4 year period, a large part of the entire surface of the Earth is covered as well as an entire volume (defined by the FC parameters) around the Earth being spanned. After the 11.4 year period, the measurements start over again with a slightly shifted starting point, allowing measurements to be compared or analyzed over a time period.

When one delves into the science related to the Earth’s magnetic field, one quickly finds that the magnetic field is not constant (as it is effected by solar weather and changes magnitude and sign) and therefore impossible to quantify in a purely static sense. The source of Earth’s magnetic field is not well known, but is best explained by dynamo theory due to the rotating core. Electric currents induced in the ionosphere also generate more localized magnetic fields. Earth’s magnetosphere extends from 80 to over 60,000 Km toward the Sun, and out to over 300,000 Km away from the Sun.

The science of measuring the dynamics of the magnetic field and correlating that data to solar weather events (such as flares and mass ejections) can greatly increase the current understanding of the effect of solar weather on the Earth’s magnetic field (including the plasma sheath and radiation effects). The Earth’s magnetic field varies significantly during solar storms, even changing sign. Data during quiet solar periods.

The interaction between universities participating in the Uni-Flower mission by gathering magnetic field data and international solar observatories could present a unique opportunity for collaboration as well as training students from varied disciplines, institutions, and continents. The driving design features of a satellite for this mission would be precision magnetometers, GPS receivers, communication link with ground, and fuel for station keeping. These simple satellites are ideal candidates for micro-or nanosatellites.

### 3.3 Orbital Solutions to Unidentified Problems

During the last two centuries of scientific discoveries, the figure of the scientist has experienced a dramatic change. Long ago, since the beginning of all the sciences, the scientist looked for mathematical tools to describe the world and phenomena around him. Then, as the mathematical tools became more sophisticated and powerful, the scientist started to spend more time in mathematical developments and research than in the observation of the natural phenomena. Today, the scientist derives mathematical truths from basic assumptions and then finds relationships that must then supported by a final “proof” or evidence of observed fact. Therefore, today the theory precedes the problem and often it actually poses the problem!

In this section, we follow the same general trend and approach: the Flower Constellation methodology gives us “solutions”, that is, the possibility of obtaining specific shapes and dynamics, and we want these shapes and dynamics to find problems for which they represent potential solutions. In other words, the approach is to concep-
tualize new space missions as we have new tools that allow us to obtain this and that.

The mission purpose associated with specific optimization criteria dictate what the optimal constellation is. Even though the problem is Pareto optimal and usually quite complex, it is also quite clear: we know what the mission purpose is, we know we want to minimize the costs (mission and maintenance), therefore let’s find out the best configuration that satisfies the various optimality constraints. The problem stated this way precludes a different approach.

Figure 11: Inclined polar circle Flower Constellation

In this section we want to present two Flower Constellation examples having peculiar and characteristic dynamics. Figure 11 shows a shape-preserving constellation made of a $N_s = 9$ satellite dish/circle ($N_p = 8$, $N_d = 1$, $F_n = 1$, $F_d = 9$, and $F_h = 0$) plus a central polar satellite. The constellation axis is equatorial, while the whole circle lies on a plane that is $15^\circ$ inclined with respect to the central polar orbit. While the outer dish is orbiting as a rigid object, all its satellites rotate within the circle itself. The inner spacecraft remains in the center of the formation. This configuration suggests of being suitable for Earth observation systems or as a huge virtual antenna. As the constellation orbits the Earth, the shape of the formation is preserved due to the FC properties.

Figures 12 and 13 show two combined Flower Constellations ($N_p = 9$, $N_d = 1$, $F_n = 1$, $F_d = 4$, and $F_h = 0$), made of $N_s = 4$ satellite each. The orbital parameters are $i = 5.2^\circ$ and $e = 0.038$. The difference between the first FC and the second one is only on the value of the argument of perigee and in the value of the first right ascension of ascending node. We have $\omega_1 = 3\pi/2$ and $\Omega_0 = 0$ for the first FC, and $\omega_2 = \pi/2$ and $\Omega_0 = \pi$, for the second. These eight satellites form a rotating three-axis ellipsoid. The shape is preserved as the constellation orbits the Earth, however
the ellipsoid itself rotates. We selected the orbital parameters in order to have this ellipsoid orbiting in an equatorial plane. However, re-orientation of the whole Flower Constellation allows us to choose any ellipsoid orbital plane.

Figure 12: Ellipsoidal constellation

Figure 13: Another view

4 Educational Possibilities

One of the beauties of the *Uni-Flower* idea is that the concept is unlimited in the scope of its missions as well as the institutions included. With the successful demonstration of the proposed Earth-orbiting Uni-Flower constellation, students (and/or PIs) could then feasibly propose Uni-Flower constellations for different applications. Such proposals could lead to international interaction and collaboration on mission design and data reduction as well as the obvious advantage of training students at the graduate and undergraduate level on mission design, data collection and reduction, orbit design, satellite design and fabrication, and spacecraft operations (including business and law). Since nano- and microsatellites are built using previously non radiation hardened components and using a combination of volunteer student project labor, they are typically designed and fabricated on a rapid timescale (12-18 months, but as quickly as 9 months). Therefore, with a solid Uni-Flower proposal in place, students could complete their satellite designs, possibly including launch and initial data analysis, in less than two years.

A recent Google search showed that at least the following universities in the United States have implemented a satellite or nanosatellite research, fabrication, and/or operations program: Texas A&M University, Utah State University, Stanford University/Santa Clara University (partnership), New Mexico State University, Montana...
State University, Boston University, Virginia Polytechnic University, Cornell University, Purdue University, University of Washington, University of Illinois/Taylor University (partnership), University of Colorado, Carnegie Mellon University, Weber State University, Iowa State University, Massachusetts Institute of Technology, San Jose State University, University of California at Berkeley, Tuskegee University, Sierra College, University of New Hampshire, University of Texas, and the United States Air Force Academy. The authors apologize to those not on the list.

Outside the US, satellite fabrication and operation research has been conducted at Ume University of Sweden, University of Surrey (England), Anahuac University (Mexico), National Autonomous University of Mexico, Aalborg University (Denmark), Danish Technical University, Bristol University (England), Open University (England), Carleton University (Canada), University of Toronto, Moscow State University, Nanyang Technological University (Singapore), Polytechnical University of Madrid, Tsinghua University (China), University of the Frontier (Chile), University of New South Wales, University of Tokyo, Stellenbosch University (South Africa), and the University of Rome.

NASA, AFRL, DARPA, Surrey Satellite Company (England), Comision Nacional de Actividades Espaciales (Argentine space agency), the TransOrbital Company (US), Meggiorin Group (Italy), Riyadh Space Research Institute (Saudi Arabia), Aeronautic Technology (Malaysia), Aprize Satellite (Argentina), and the Amateur Radio Association have all recently participated in nanosatellite design and fabrication leading to launch. The authors wish to apologize in advance for any institution or agency that was inadvertently not mentioned in this listing.

Any satellite project becomes interdisciplinary in the fact that satellites must be complicated in order to function and survive in space. Nanosatellites are not required to be as complicated as traditional satellites due to their specifically designed purpose. However, many interdisciplinary functions are still required. For example, thermal, power, and structural parameters must be met in the design phase while the design and operation of the instrument must also be investigated. While engineers and scientists (from almost all disciplines) typically design and build the satellites, opportunities for other degree seeking students exist. Journalists and historians have written articles detailing the progress; physicists, chemists, mathematicians, geographers, geoscientists, agricultural specialists, meteorologists, oceanographers, sociologists and historians have analyzed data from satellite projects alongside the engineers.

A single university, such as Texas A&M (TAMU), has numerous opportunities to strengthen interdisciplinary ties through a nanosatellite project. The Department of Aerospace Engineering at Texas A&M has a rich history in satellite design, star tracker hardware and algorithm development, and attitude determination and control. For example, if TAMU were tasked with flying an ocean altimeter for a tsunami detection and warning system, a secondary mission could be the technology demonstration of a novel star tracker and/or attitude determination algorithm. On such a
project, there would feasibly be several departments involved in designing and operating the satellite as well as analyzing the data. In designing the satellite, the Aerospace Engineering, Electrical Engineering, Mechanical Engineering, Computer Science, Oceanography, Ocean Engineering, Physics, and Mathematics Departments could feasibly be involved. In analyzing the data, the Oceanography Department, Ocean Engineering Department, Physics Department, Computer Science Department, Electrical Engineering Department, Meteorology Department and the Remote Sensing Research Group could feasibly be involved.

This example fails to mention the possibility for English and Journalism students to participate by detailing the project over its lifetime (from conception to end of usefulness) through articles and reports. Business students could also be introduced to the project for accounting and scheduling purposes, and Political Science and (Pre-)Law students could become involved in any policy and/or legal issues surrounding launch and operation—especially on international projects.

Mandatory educational outreach programs could also be set up (specific to each funded mission) where the PI is required to provide information and data to anyone interested in a format that anyone could understand. The PI could partner with a set of elementary and/or secondary schools to do public outreach and offer real-time data in the classrooms, and offer an explanation of the mission and data sets freely on the Internet.

5 Administrative Concerns

As previously noted, any Uni-Flower project would be a massive undertaking—especially from the administrative, funding, and time requirement standpoints. It seems logical that one institution would serve as the lead on a Uni-Flower research project to ensure time constraints are met and necessary communication is uninterrupted. Assuming that the lead institution was the one who proposed the Uni-Flower project, this institution could then be in charge of defining the engineering and scientific purposes of the satellites, securing a launch vehicle and launch date, and ensuring that each participating partner met necessary time lines.

Each institution would then be responsible for acquiring its own funding for the project. Administrative duties could also be contracted out to any technical firm whose job it would be to ensure compliance with technical and schedule requirements, basically giving this firm the title of project manager. The lead institution could also serve as the hub for satellite operations (requiring a local mission control) as well as a hub for data collection and distribution. Having centrality of the data would allow the PI to implement the public outreach portion more effectively.

This type of administrative structure gives rise to a possible consortium of participating universities. Uni-Flower proposals could then be reviewed on a regular basis with
one being picked to pursue during a given time period. When that mission lifetime expires, a new proposal (and research project) could then be assumed. Again, many other administrative models exist and could be implemented.

6 Conclusion

Possible Uni-Flower missions are described in detail with options left open for many more. Details about the orbit and satellite design, educational opportunities, and university interaction and collaboration have been discussed. Hints for the administrative and managerial aspects of a Uni-Flower mission are presented. Finally, any Uni-Flower type mission would require a significant investment in time and effort (including funding and administrative duties), but these type missions should be given considerable attention for all of their scientific and educational advantages.

7 Acknowledgments

The authors wish to greatly thank Dr. Helen Reed and Dr. John Junkins from the Aerospace Engineering Department at TAMU for their discussions on educational possibilities and management of a project of the scope of a Uni-Flower. We also wish to thank Dr. Patrick Lynett from the Civil Engineering Department (Ocean Engineering group), and Dr. Jerry North and Dr. Mark Lemmon from the Atmospheric Sciences Department at Texas A&M University for sharing their valuable time and experience in Earth observation missions.

The authors finally wish to encourage an open dialogue of the ideas presented in this paper (contact information is listed at the bottom of the first page for both of the authors).

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