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Developments in Commercial Near-Space Systems

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DEVELOPMENTS IN COMMERCIAL NEAR-SPACE SYSTEMS

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Abstract

An Arizona company is nearing commercial deployment of a wire less communications system based on platforms which free-drift on balloons at 31,500 meters (100,000 feet). The system provides two-way wireless messaging to existing commercial devices in a 570-km (360-mile) diameter coverage circle. The system is based on a constellation of small (less than six pounds), low cost (a few hundred dollars each), short life (24 hours) expendable electronics packages launched on conventional weather balloons, which free drift with the uniform winds in the stratosphere. A seventy-platform constellation covering the continental United States (US) is planned to enter commercial operations within a year. This new type of constellation can service several traditional space missions on a low-cost and responsive basis because the major barriers related to rocket launches are eliminated. Also since the platform is over twenty times closer to the earth than even a low earth orbit satellite, radio link budgets and optical resolutions are greatly improved.

These stratospheric platforms offer several advantages in the areas of development time, cost, logistics, and responsiveness. Since the platforms are over 20 times closer to the user than a satellite, only move at tens of miles per hour, and are not subject to long-term exposure to radiation in the space environment, they can be developed using the components and processes widely used in the commercial electronics industry. Since the platforms make use of mass production techniques and mass-produced components, the cost per platform can be very low cost. Since the platforms are launched on weather balloons which have been in operation on a daily basis from thousand of sites for over half a century and are produced using readily available contract manufacturing resources, the logistics are well established and current launch sites provide coverage to virtually the entire landmass of the earth. The platforms can be prepared for launch and put on station in only two hours from a site a couple hundred miles from the desired area of coverage. With Moore's Law continuing to increase the capability and reduce the costs of electronics, the velocity of technology is everyday increasing the advantage of systems that can be developed and deployed quickly.

This paper details the development of the current wireless communications network currently in pre-commercial testing and then discusses the range of possible applications for the technology including: remote imaging, wireless voice and high data rate applications, signal intelligence, bi-static radar and others. It also offers several comparisons of traditional satellites versus this new technology on important capability metrics.

Overview

Motivated by a need to cost-effectively fill gaps in wireless coverage, Space Data Corporation of Chandler, Arizona, is developing and deploying a constellation of balloon-borne "cell towers." Capitalizing on well-established 60-year-old weather balloon technology, the company is carrying lightweight communication payloads to 30,000 meters to provide wireless services where they are currently unavailable due to economics and terrain. The goal is to complement existing terrestrial carriers as well as support new services heretofore possible only via satellite. Unlike satellites, the network is compatible with the existing wireless user devices already in wide-spread use. The result is an extremely low-altitude platform capable of carrying user-tailored payloads for a variety of communication and data collection applications.

System Concept

How the System Works. Every 12 hours, a SkySite™ Platform will be launched from each of 70 launch sites across the continental US to form a SkySite™ Constellation. Space Data has developed a proprietary control algorithm that can control the operating height and the ascent rate of a SkySite™ Platform. The altitude can be maintained or changed by venting gas or releasing ballast. It takes about 100 minutes for each untethered SkySite™ Platform to ascend to 30,000 meters. A meteorological payload may also be attached to the SkySite™ Platform to take atmospheric measurements upon ascent and jettisoned as ballast upon reaching 30,000 meters. Upon reaching this height, the constellation forms an overlapping field of coverage circles that stretches over the entire continental US as shown in Figure 1. Wind patterns at 30,000 meters are very predictable since they are nearly twice as high as the nearest cloud, three times higher than the jet stream, and several times higher than the highest mountain. Basically the wind patterns are dominated by large global circulation flows, which are uniform and have predictable seasonal variations. Over 60 years of National Weather Service meteorological data is available for analysis of the winds in all conditions. Simulations using this data verify that the winds are uniform enough to maintain an evenly spaced constellation for at least 12 hours. Once aloft, the future position of each SkySite™ Platform in the constellation can be projected. Based on this predictive knowledge, Space Data's SkySite™ Control Center (SCC) can proactively launch individual SkySite™ Platforms as needed to plug potential developing coverage gaps or adjust the altitude of individual SkySites™ Platforms to a new level with preferential winds to keep the constellation uniformly spaced.

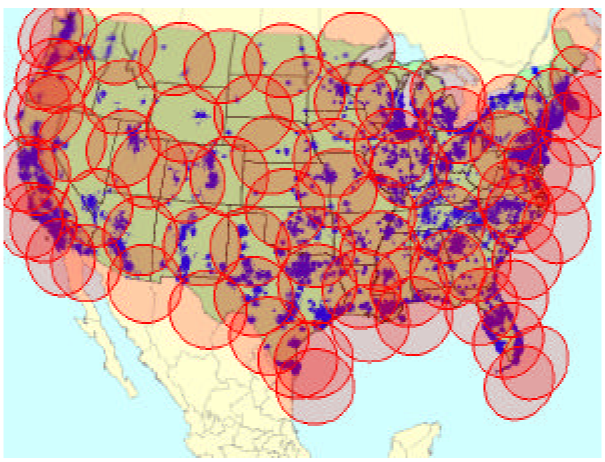

Figure 1: Coverage provided by constellation of 70 SkySite™ Platforms overlaid on the combined coverage of the terrestrial dedicated messaging networks.

Each 12 hours, a new constellation of 70 SkySite™ Platforms will be launched. The previous constellation will remain in the stratosphere for another 12 hours or more and is placed in "Standby" mode. Thus, at any given time, two constellations will be afloat. That way, if a SkySite™ Platform from the second constellation drifts out of position or is lost for any reason, a standby SkySite™ Platform from the previous constellation may be reactivated to plug coverage gaps. This redundant system of SkySite™ Constellations combined with the SCC's predictive meteorological system ensures that the SkySite™ Network will consistently deliver the required uptime demanded by today's wireless consumer.

Functional Description of Network. The SkySite™ Network is diagrammed in Figure 2. Each SkySite™ Platform, like a ground-based wireless messaging tower, transmits and receives messages to and from subscriber devices. When a partnering carrier has information (either a message or a voice stream) to send to the Space Data system for transmission to a subscriber device, the data will be relayed to the Space Data Network Control Center (NCC). The NCC will determine which SkySite™ Platform is currently over the desired subscriber device and will send the data to the regional ground station that is presently tracking that specific SkySite™ Platform. The SkySite™ Platform then will retransmit the data down to the subscriber device. For data flowing from the user to the carrier, the data path will flow in the opposite direction.

The SkySite™ Network consists of 5 subsystems listed below and described in detail:

1. SkySite™ Platform
2. Launch Facilities
3. Ground Stations
4. Network Control Center (NCC)
5. SkySite™ Control Center (SCC)

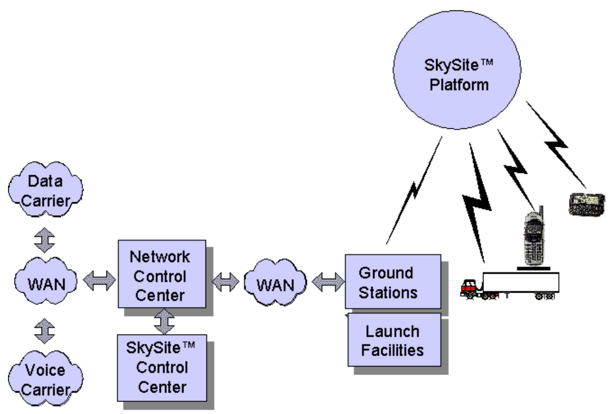

Figure 2: The SkySite™ Network

SkySite™ Platform. The SkySite™ platform consists of two major subsystems: the balloon; and the payload. The SkySite™ Platform is shown in Figure 3.

<u>The Balloon</u>: The balloon is a hydrogen or helium filled latex balloon that provides lift for the payload and meteorological package. At launch, the balloon lifts the payload and meteorological package at approximately 300 meters per minute up to a hover altitude of

approximately 30,000 meters. The lifting gas is partially vented from the balloon to slow and finally stop the ascent. During hover, the SkySite™ Platform vents gas or drops ballast in order to maintain the desired altitude. The ballast system consists of a non-hazardous liquid that can be incrementally released.

The Payload: The payload consists of the communication and control electronics, control mechanisms, and power source necessary to provide digital wireless coverage up to 24 hours. The communication and control electronics include the processor and software that control the Global Positioning System (GPS) receiver, the SkySite™ control electronics, and the communication transceiver. The communication and control electronics coordinate and command the SkySite™ Platform subsystems, providing communications relay between subscriber devices and ground stations, receiver and transmitter control, communications buffering, frequency and frame transmission control, internal timing calibration, GPS data collection and processing, venting, ballast release, and flight termination.

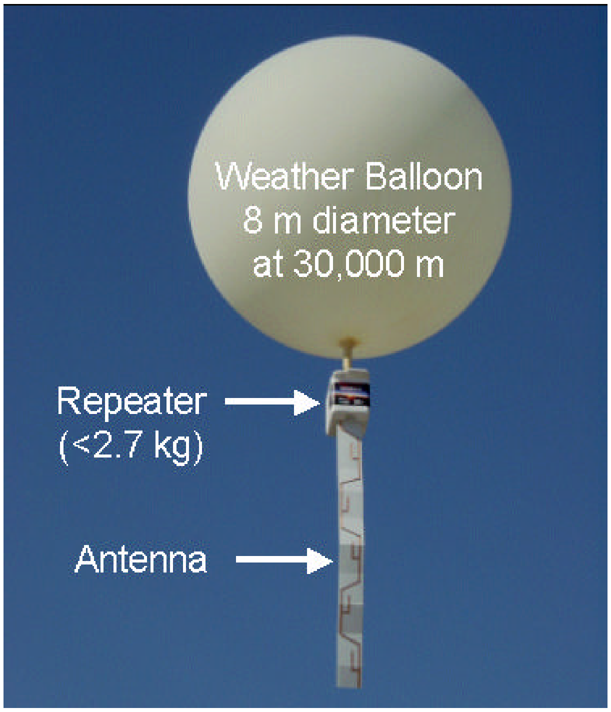

Figure 3: SkySite™ Platform with Antenna Deployed

The SkySite™ Transceiver and Digital Signal Processor (DSP)-based baseband repeater receives radio signals from a ground station or subscriber device, converts these signals into digital data, corrects errors, and retransmits the corrected data to the intended ground station or subscriber device. DSP technology provides improved radio frequency link margin and programmability for standard wireless communication protocols (e.g., CDMA, GSM/GPRS, iDEN, etc.).

A specially designed antenna permits the SkySite™ communication electronics to provide an even power distribution over the entire coverage area. A GPS receiver provides highly accurate timing used for SkySite™ Platform communication and position data to the SCC for the entire SkySite™ Platform flight.

In order for the SkySite™ Platform to level off and maintain an altitude of 30,000 meters, the onboard control processor executes an advanced control system algorithm based on GPS data, which vents lifting gas or releases environmentally benign liquid for ballast, which evaporates into the atmosphere.

Additional onboard flight control includes a balloon release mechanism and a parachute. At the end of operations at altitude, the balloon release mechanism is activated and the SkySite™ Platform falls safely back to earth on its parachute. The SkySite™ power supply consists of a battery pack of high power density, D-cell-size lithium sulfur dioxide ($LiSO_2$) batteries. The Environmental Protection Agency has classified $LiSO_2$ batteries as non-hazardous waste when they are completely discharged. When these batteries are fully discharged, the result is an environmentally benign salt.

The Federal Aviation Administration (FAA) allows unmanned, free-floating balloons to carry up to two, 2.7-kg (6 lb) payloads without requirements to carry transponders or notify airmen, and no restrictions on visibility. The reason is commercial aircraft are designed to safely withstand a 3.6 kg (8 lb) bird strike on empennage structures. In the last 60 years nearly 5 million weather balloons have been flown in the US without any recorded damage to civilian, commercial or military aircraft.

Figure 4: A SkySite™ Platform Launch

Launch Facilities. A launch facility is a small physical structure that houses the materials and personnel needed to launch SkySite™ Platforms. Each launch facility contains a supply of SkySite™ Platforms, cylinders of lifting gas, and latex weather balloons. Figure 4 shows the launch of a SkySite™ Platform.

Ground Stations. Co-located near each geographically distributed launch facility is a ground station. The ground stations provide the communications interface between SkySite™ Platforms and Space Data control centers. Each ground station includes the network router, transmitters, receivers, antennas and controllers, diplexers, monitoring and test equipment, uninterruptible power supply, backup generator, and air-handling unit.

Because SkySite™ Platforms are untethered and free-floating, a single ground station may need to maintain communications with up to four of them at any given time. Using steerable antennas, antenna controllers, and antenna pointing commands received from the SCC, a ground station will automatically reposition its antennas to maintain communication with the SkySite™ Platforms as they rise and set over the horizon.

Ground station transmitters will perform the modulation necessary to transmit subscriber communications and commands to the SkySite™ Platform. Ground station receivers will demodulate subscriber communications and SkySite™ Platform status information received from the SkySite™ Platform and send that data to the NCC and the SCC respectively. The ground station diplexer permits the ground station transmitter and receiver to use a single antenna for transmitting and receiving information to and from a SkySite™ Platform. To ensure high network availability and reliability, redundant systems are designed into every ground station and each ground station has redundant communication links back to the Space Data control centers.

Network Control Center (NCC). The NCC is the central communications, network switching and management facility for the Space Data system. The NCC serves as the point of connectivity between partnering carriers and their customers. The NCC routes subscriber communication to the proper SkySite™ Platform via a ground station, stores device location and usage information, and provides monitoring and test functions for overall network management.

When fully deployed, the SkySite™ Network will have two NCCs. Both sites will have the ability to provide backup and recovery for the alternate site in the event of a catastrophic event such as an earthquake or flood. This backup configuration provides a high level of fault tolerance since no single hardware failure can impact the network. The NCC facilities will have uninterruptible power, physical site security, and a controlled environment.

Device usage and location information is stored in a device location and status database. The status of whether a device is registered and authorized for Space Data service is also stored in this data repository. Device location is determined by communication from the wireless device.

To guarantee sufficient network capacity, the amount of subscriber traffic transmitted on a SkySite™ Platform will be tracked and compared with capacity limits of a SkySite™ Platform. This function will be automatically performed by capacity forecasting applications running in the NCC. If usage data trends or instantaneous usage data approaches capacity limits for a given SkySite™ Platform, network operations personnel will be automatically alerted so that additional capacity can be deployed in that area.

SkySite™ Control Center (SCC). Whereas the NCC is responsible for subscriber communication and overall network connectivity and management, the SCC is in charge of monitoring and controlling the SkySite™ Constellation. Similar to the NCC, Space Data will have two SCCs when the system is fully deployed and each site will have the ability to provide recovery for the alternate site in the event of a major network outage. This complete system redundancy improves network reliability and availability by eliminating single points of failure. To take advantage of economies of scale and natural synergies, the SCC will share facilities with the NCC thus benefiting from common uninterruptible power and physical site security. Major subsystem functions at the SCC include SkySite™ Platform location and status, antenna tracking, coverage forecasting, SkySite™ Platform manual commanding, and meteorological data processing.

All SkySite™ Platforms are equipped with a GPS receiver providing latitude, longitude, altitude, and heading data for each SkySite™ Platform. This information is transmitted to the SCC via ground stations and stored in the SkySite™ database for each SkySite™ Platform flight. In addition to SkySite™ Platform location and heading, data pertaining to active/standby status, total vent time, total ballast release, time in operation, and estimated battery life is maintained in this data repository.

In normal operation, embedded processors and applications will automatically perform the routine functions of SkySite™ Platform control. However, if status data indicates that a SkySite™ Platform is operating outside acceptable limits or is experiencing an anomaly, SCC personnel have the ability take control and manually transmit commands to SkySite™ Platforms in order to maintain the integrity of the constellation. Examples of such commands would be to change operating altitude, drop a specified amount of ballast, vent for a specific period of time, go into standby or active mode, change operational frequencies, or terminate the flight.

In order to ensure that coverage is there when subscribers need it, the location and heading of SkySite™ Platforms, the current status of the constellation, and meteorological data gathered by the NWS is used to anticipate any possible coverage gaps that may form over the next 12 hours. This coverage forecasting data is provided to SCC personnel so that appropriate action can be taken before any coverage gaps develop.

Another function performed by the SCC applications is automatically tracking SkySite™ Platforms by issuing antenna pointing commands to the ground station antennas. The SCC uses the location of the ground station and the location of the SkySite™ Platform to determine the azimuth and elevation of the antenna in order for the antenna to track and maintain communication with the SkySite™ Platform.

Advantages versus Traditional Space Systems

Overall, SkySite™ Systems are lower cost, more flexible, and offer less risk than many traditional space systems. This is largely due to the dichotomy between rocket launched systems, which physics dictates must be large to be efficient, and microelectronic and micromechnanical systems, which account for much of today's technology advances. SkySite™ Systems do not suffer from this dichotomy.

Many of the aspects of rocket-launched systems are determined by the rocket delta velocity equation:[1]

$$\Delta V = \sum_{n=1}^{N} \Delta V = \sum_{n=1}^{N} g I_{sp_n} \ln \mathbf{MR}_n \qquad (1)$$

where: *DV* = *change in velocity*
N = *number of stages*
g = *acceleration of gravity*
I_{sp} = *specific impulse of rocket*
MR = *mass ratio*
= *(mass with propellant / mass without propellant)*

Several of these variables are essentially fixed. Each orbit requires a given *DV*, which is at least 9.1 km/s for a Low Earth Orbit (LEO). Earth's acceleration of gravity is fixed. Specific impulse for even the best chemical propellants has a theoretical maximum at sea level of 390 seconds for liquid hydrogen and liquid oxygen.[2] Easier to handle solid propellants have lower specific impulses than liquids, typically 265 seconds or less.[3] The space shuttle main engines achieve specific impulses of 363 seconds or 93% of theoretical maximum.[4] It is of course desirable to minimize the number of stages because each additional stage adds complexity and cost. This leaves the mass ratio as the one real variable that can be engineered. For a single stage rocket with engines as efficient as the shuttle to get to orbit, the mass ratio must be more than 13, which means the initial mass of the rocket must be 93% propellant at launch. Add the complexity of a second stage and the rocket is 84% propellant at launch in the case of the Delta IV-M.[5]

With only 7% to 16% of the rocket's launch mass being structure and payload, the primary design objective is generally to reduce the structural mass to a minimum so more payload can be carried. This can be done through the use of advanced materials and/or detailed stress analysis to minimize the required design margins, although this increases costs and risks if not well proven. By far the simplest way to reduce structural weight as a percentage of the whole rocket is to make the rocket big. This is because if one doubles the size of a tank, the weight of the tank goes up by roughly a factor of four, whereas the volume of the tank (and thus the mass of propellant it can hold) goes up by roughly a factor of eight. So physics dictates there are large economies of scale for making rockets big. However, big rockets mean in big funding requirements, long design cycles, large specialized launch facilities, and big risks of failure as large payloads are generally more expensive and more strategic than small payloads. So in an industry where even a couple of orders of magnitude improvement in launch costs would be revolutionary, we seem to be against a theoretical wall.

Contrast this with the seemingly unstoppable advances in semiconductor fabrication, which have increased by over 100 million times the number of transistors on a microchip since the space race began. Indeed, most of the technical advances of our time have been the direct or indirect result the relentless trend of electronics, and, increasingly, mechanical systems, becoming smaller and smaller. Moore's Law states that the number of transistors in the average integrated circuit doubles every 18 months.[6] This has led to relentless decreases in the average cost per transistor as shown in Figure 5 coupled with relentless increases in the cost of the tooling to make integrated circuits as shown in Figure

6. A new silicon fabrication plant now costs nearly $10 billion. Intel Corporation is currently developing technologies that will continue these trends for at least another decade. Unfortunately, the space system designer who can now perform the same functions with a much smaller satellite finds that physics dictates that small launch vehicles are much less cost efficient.

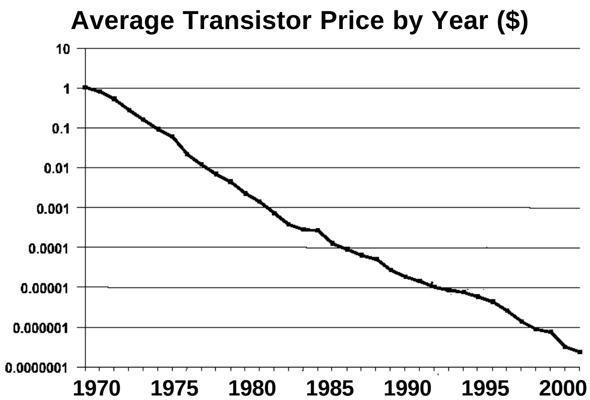

Figure 5: Average transistor price has been cut by half every 18 months for over a third of a century.[7]

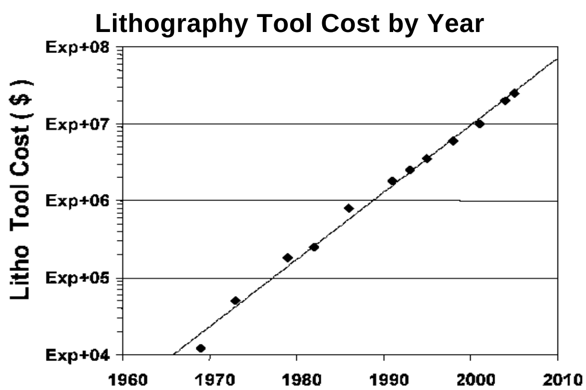

Figure 6: Average cost of a silicon fabrication plant.[8]

The results of these trends have profound impacts on space systems. The result is a trend where most of the cost of a product is in its design and tooling not in the incremental cost of the individual unit. Thus, we are seeing the same revolution brought on by the printing press. Before the printing press it did not make sense to have a newspaper because every character was scribed by hand, but the printing press made the cost of an incremental copy effectively nothing. Now we have newspapers with AM editions and PM editions. We read the newspaper for five minutes and throw it away.

While the design cycle, production run, and useful life of a typical consumer electronics product is measured in months, the design cycle, production run, and life of most space systems are measured in years or even decades. Because of the velocity at which technology is advancing, space systems are increasingly falling behind the technology curve as shown in Figure 7. For example, Sandia National Lab and Maxwell Technologies are developing a radiation hardened Pentium© processor. The commercial version of this processor entered commercial use in 1993. The initial, flight-qualified, radiation-hardened version will be available in September 2003.[9] If we assume it takes two years to design it into a new satellite and launch the satellite, the processor will already be 100 times slower than the typical personal computer selling for $1,000 at launch. After spending 10 years it orbit the performance will be over 10,000 times slower than a typical personal computer selling for $1,000 in 2015.

Thus to take advantage of Moore's Law, space systems would ideally be composed of small, short-life, effectively disposable platforms that are decoupled from the physics of rockets. This is exactly what SkySite™ Platforms are. Since SkySite™ Platforms are 20 to 50 times closer to the earth than LEO satellites, an added advantage is radio link margins are hundreds of times stronger and the required apertures for optics are 20 to 50 times smaller. Therefore, the SkySite™ Platform approach yields several advantages over satellites.

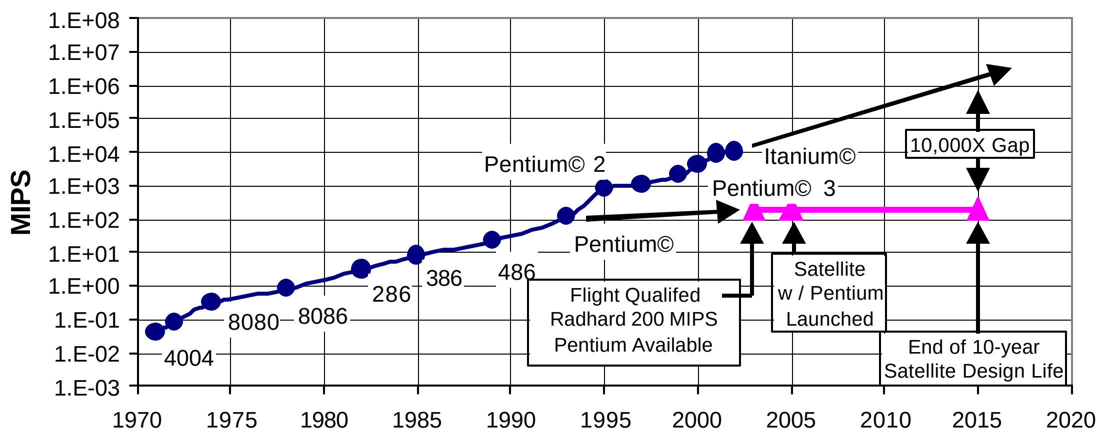

Figure 7: Performance gap between commercial and radhard microprocessors is growing.

Benefits related to user equipment:

- SkySite™ Platforms are from 20 to 50 times closer to the user than a LEO satellite and 1,000 times closer than a GEO satellite, which enables smaller, lighter user equipment with longer battery life.
- There is no large relative motion between the SkySite™ Platform and the user, which would require the use of special user equipment to compensate for the channel frequency Doppler shift as with LEO satellites.
- SkySite™ Systems can use the same equipment as a terrestrial-based system, which greatly reduces the cost and time of development because suitable user equipment is already being mass-produced.
- The SkySite™ Systems can work cooperatively with terrestrial systems whereby terrestrial systems cover cities, which require high power / high capacity transmitters, and the SkySite™ System covers rural areas, which require low power / low capacity, broad area transmitters.

Benefits related to covering a targeted geography:

- Unlike LEO satellites, which must go around the earth in about 90 minutes, SkySite™ Platforms move slowly and can be deployed over just one country or region of interest.
- LEO systems must cover the entire earth even though only one quarter of the earth is land and a much smaller fraction has any population or profitable market. Thus, three quarters of the capacity is wasted with LEO systems.
- Because a SkySite™ System can be geographically targeted, higher capacity SkySite™ Platforms can be flown over high demand areas and less expensive, low capacity SkySite™ Platforms can be flown over the low demand areas.
- Startup costs are minimized because SkySite™ Systems can be rolled out one country or region at a time, whereas LEO satellite systems must roll out capacity for the entire earth at once and obtain regulatory approval and start marketing in every country on earth simultaneously in order to not waste capacity.

Benefits related to not using rockets:

- Launch costs are about $25 per pound for balloons versus $10,000 per pound for rockets.
- SkySite™ Systems are launched in very small increments of capacity (a small region for 12 hours), whereas satellites must be launched in huge increments of capacity because they are designed for lifetimes of 5 to 15 years.
- During a satellite launch, 5 to 15 years of capacity for a large fraction of the earth is at risk due to the potential of the rocket exploding.
- A satellite system developer must finance 5 to 15 years of capacity up front, whereas a SkySite™ System developer must only finance about a month of capacity up front. This ability to have "just-in-time capital expenditures" offers great improvements in return on investment when the time value of money is considered.
- A satellite system developer must size the capacity of the system for anticipated end of life demand 5 to 15 years out. During the initial years of a system the capacity requirements are often minimal and thus capacity is wasted. A SkySite™ System operator can scale the capacity every day to match demand.
- SkySite™ Platforms have a development cycle typical of consumer electronics (12 to 18 months) whereas satellites take 2 to 3 years to design and 18 to 24 months to build.
- A SkySite™ Platform can be placed on station by one person in less than two hours versus a satellite taking hundreds of people months or even years to install.

Logistics of SkySite™ Platforms

SkySite™ Platforms make use of the same logistics train as weather balloon launches, which has been developed over the last 60 years. There are nearly a thousand sites launching weather balloons twice per day throughout the world. Attaching a SkySite™ Wireless Repeater to these existing launches provides coverage to nearly all the populated regions of the world as Figure 8 shows. Fixed launch sites are so pervasive that the 2000 World Meteorological Organization (WMO) database even listed three launch sites in Talaban-controlled Afghanistan.

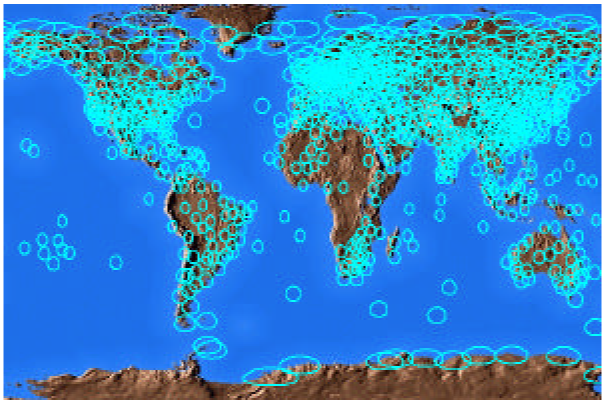

Figure 8: Projected coverage if SkySite™ Wireless Repeaters were attached to weather balloons, which launch twice per day from nearly a thousand sites.

Since every branch of the military engages in operations affected by weather, there are personnel experienced with weather balloon launches already in the services. As the WMO requires nations to launch weather balloons at a geographic spacing through the world, there are systems to launch SkySites™ Platforms in all weather conditions from ships, airplanes, and portable buildings, as shown in Figures 9, 10, and 11.

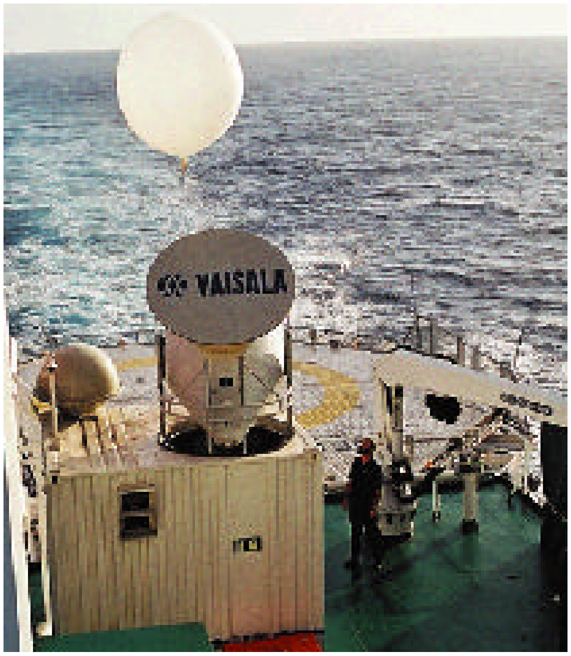

Figure 9: Shipboard launch capability.[10]

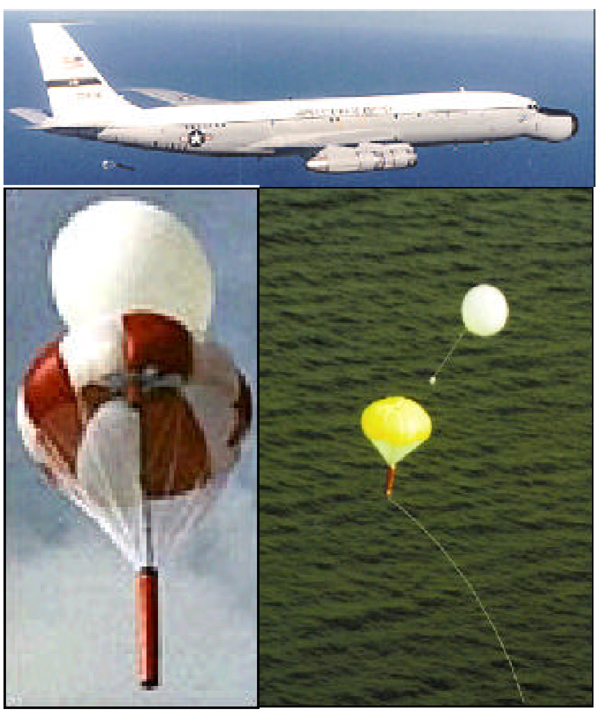

Figure 10: Airborne launch capability.[11]

Figure 11: Portable building launch capability.

Figure 12: Automated launch capability.[12]

There are even automated launchers that can be filled with expendables to unattended launch of up to 24 SkySite™ Platforms as shown in Figure 12. Even open fields can be used to launch balloons as demonstrated by actress Lindsay Crouse in the 1996 movie <u>The Arrival</u> at the opening of scene 19. Figure 13 shows a bird's eye view of the setup for field launching. The balloon in inflated inside the yellow canvas tent then released by pulling a Velcro© flap. Staking down the yellow tent allows operations in high wind conditions. If compressed hydrogen or helium is unavailable, hydrogen can be provided by dipping a chemical hydrogen generator (ML-303/TM) in water.

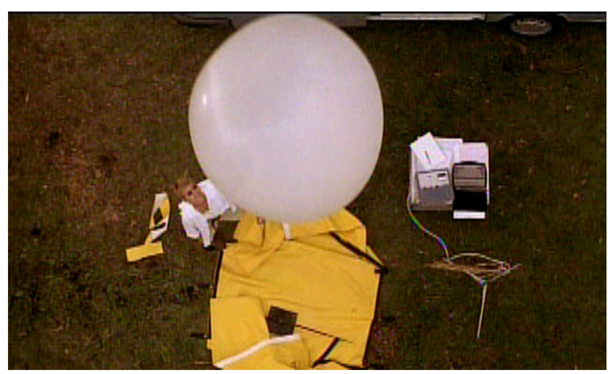

Figure 13: Bird's eye view of open field balloon launch as shown in 1996 movie <u>The Arrival</u>.

Table 1: Comparison of Key Aspects of Rockets and Weather Balloon Launches for 1998.

	Rockets	Weather Balloons
Launches per year worldwide	74	more than 800,000
Total payload per year worldwide	526,000 pounds	more than 550,000 pounds
Launch cost per pound	$10,000	$25
Global launch sites	10	1054
Years since initial operation	40	80
Lead time for launch	12-18 months	20 minutes
People required for launch	hundreds	1

Table 1 compares some key metrics of the orbital space launch industry and the weather balloon industry. Although the average payload for a weather balloon is now less than a pound, in aggregate more mass of total payload is launched above 100,000 feet every year by weather balloons than all the space launches combined. These numbers are actually for the year 1998 before the recent decline in space launch activity. The cost per pound on station is about three orders of magnitude lower for weather balloons. As mentioned above, there are a hundred times more established launch sites. Weather balloons have twice the heritage of orbital launches and can be prepared for launch in 20 minutes by a single person. Unlike space launches which are anything but routine, weather balloon launches have been routine for the better part of a century. The NWS office in St. Cloud, Minnesota once received an award for going 17 years straight, launching twice per day everyday, without missing a single launch.[13] This is in spite of Minnesota's climatic extremes of –40 degree winter days, -100 degree wind chills, high winds, sleet storms, blizzards, tornados, hot humid summer days, and thunderstorms.

Another point of comparison can be made with individual space systems. For instance the Orbcomm LEO satellite system provides text messaging capabilities similar to Space Data's initial SkySite™ Network. Each Orbcomm satellite has one 9600 bps transmitter and six 2400 bps receivers. As there are generally two Orbcomm satellites over the continental US at any one time, that makes for a total transmit capacity of 19.2 kbps and a total receive capacity of 28.8 kbps for Orbcomm. Space Data's initial messaging network has 70 SkySite™ Platforms over the continental US at any one time. As each platform can transmit at 6400 bps and receive at 9600 bps, the total continental US transmit capacity is 448 kbps, and the total receive capacity is 672 kbps, or 23 times Orbcomm's transmit and receive capacities. Orbcomm costs more than $500 million to deploy. The messaging SkySites™ Platforms cost $300 per launch and 50,000 launches per year are required to service the continental US. That is $15 million per year in expendables or only 3% of the up front cost of Orbcomm.

Another way to compare is by examining a cost metric such as average cost to cover a million square kilometers for one hour. With a LEO satellite messaging system we assume the satellite costs $6 million each and eight are launched on one rocket, which costs $20 million. Thus, the average cost per satellite on orbit is $8.5 million. Assuming the satellite has a 3-year design life, the cost per hour of coverage is $8.5 million / (3 x 365 x 24) = $323 / hour. Each satellite can cover a circle defined by a minimum user elevation angle of 10 degrees, which is an area of 13.7 million square km. Since the earth is three quarters ocean or ice and each LEO satellite coverage is uniformly distributed over the earth, the effective land coverage of a LEO satellite is 3.4 million square km. Thus, the cost metric is $95 / hour / million square km.

A SkySite™ Messaging Platform costs $300 per launch and provides 12 hours of coverage. Space Data has successfully flown SkySite™ Platforms at altitudes up to 38,700 meters (127,000 feet). Since the platform is so much closer to the user, a minimum elevation angle of 5 degrees can be supported. This gives a coverage area of 0.37 million square km. Thus, the cost metric is $68 / hour / million square km. Thus, the system cost for SkySite™ Platforms is less even when the time value of money is ignored, yet they provide several times the capacity of a satellite system.

Applications of SkySite™ Technology

Beyond the narrowband data services planned for Space Data's initial rollout, the versatile balloon technology of the SkySites™ Platform shows great promise for a wide variety of applications currently supported by more expensive platforms or, in some cases, not at all practical due to various risks associated with carrying particular payloads into challenging or even hostile areas.

Telemetry. The wireless telemetry market is defined to include any application where data is transferred over a wide area between two or more machines for the purpose of monitoring, recording or controlling. An example of a telemetry application is when an oil company or a utility needs to monitor the performance of its systems via wireless sensors deployed in remote locations. Other telemetry applications include sending data from vending machines to manage inventory and restocking orders, and security applications where wireless messaging is built into home security systems as a backup network to vulnerable terrestrial phone lines. The benefits of telemetry capabilities include operational and cost efficiency in the form of better system monitoring, automated alarms, more responsive customer service, reduced labor costs, and remote repair/maintenance alerts.

Automotive Telematics. Automotive telematics applications combine wireless communications with location sensing technology to provide in-car services such as roadside assistance, stolen vehicle tracking, automatic crash notification (airbag notification), remote door unlocking, remote engine diagnostics, navigation assistance, and concierge services. Most of the automobile manufacturers have invested in telematics technology and are currently offering telematics services on high-end vehicles. The best example of telematics services is General Motors' OnStar service.

Automated Vehicle Location and Trailer Tracking. Automated Vehicle Location and Trailer Tracking (AVL and TT) include an array of applications that use wireless communications to transmit data from a sensor mounted in a vehicle. The data is used to locate and manage the movement of a fleet of vehicles as well as monitor operating parameters such as engine status. In addition, AVL applications include asset tracking capabilities where shipping companies use inexpensive sensors in conjunction with a wireless network to track cargo as it moves from point of origin to final destination. By deploying asset-tracking technologies, commercial trucking companies can gain operating efficiencies through better fleet management and utilization. User equipment the size of a pager is available for $200 each and includes augmented GPS, which can track a package inside a covered truck trailer. Commercial companies are working on key-fob-sized version of these devices expected to sell at a price point of $99 that will allow tracking of pets and children.

Wireless Voice and High Data Rate. Both these modes are planned successors to our initial low data rate messaging and telemetry applications. The balloon control issues remain the same, with the possible variation of a heavier payload to support these more power-hungry modes, or (better yet) more exotic power sources. Space Data is developing a patent-pending technology that uses fuel cells as a power source. The fuel cell burns the hydrogen from the balloon. This produces water, which is stored and used as ballast. This provides power densities much greater than primary batteries.

Remote Imaging. As with any platform providing the "high ground" perspective, Space Data's SkySite™ Platform can support imagery requirements. In fact, the balloon-based solution provides a low-cost alternative to both Government and commercial satellite options, as well as airborne capabilities such as UAVs. This is literally a "back to the future" application as in 1955 President Eisenhower approved Project Genetrix, which launched 516 camera-equipped balloons from Western Europe before the U-2 spy plane was available.[14] These balloons drifted over Eastern Europe, the Soviet Union, and China. Film canisters were picked up in airspace over the Western Pacific. The program was a failure with only forty-six payloads recovered. The Russians recovered several balloons, which they called "espionage balloons" in the world press. Given that there were no integrated circuits or GPS receivers at the time, each balloon was fifty feet in diameter and had a payload that weighted 1,430 pounds.[15] SkySite™ Imaging Platforms are now possible because the size of a transistor has shrunk by a factor of a billion since 1955 and GPS receivers weighting less than 6 grams and costing less than $35 are available, which provide the balloon's position within a few meters.

Table 2: SkySite™ Payload weight allowances.

	Float Altitude	
Balloon Size	**20,000 m**	**30,000 m**
1500 gram	20 kg	4.5 kg
2000 gram	30 kg	6.5 kg
3000 gram	44 kg	9.5 kg

Weight allowances (see Table 2) can support a substantial imagery device with high-resolution optics, or something as simple as an off-the-shelf 35mm camera. For instance a Canon Rebel G camera with a 300 mm lens has a mass of less than 0.8 kg and an aperture of 6 centimeters. In addition to solutions that require payload recovery, a SkySite™ Platform can provide real-time video and still photography relayed to the ground over an RF link. Lightweight, low-power CCD image capture devices are now built into 5 mega pixel consumer cameras at retail for less than $1,000.

Governments, city planners, farmers, environmentalists, mapmakers, and real estate developers all rely on aerial or satellite photos. There are commercial companies in the US developing remote imaging satellites that will take black and white photos with half-meter resolution. Until recently, this resolution was only available from classified spy satellites. These satellite systems and associated ground equipment cost over $200 million each. The equation below defines the best resolution of a camera if its optics are perfect and thus the resolution is diffraction limited:[16]

$$d = 1.22 \frac{l d_i}{l} \qquad (2)$$

where: δ = resolution (meters)
λ = wavelength of light (meters)
d = distance to target (meters)
l = diameter of exit pupil (meters)

To get half-meter resolution from a satellite 680 km above the earth in the 0.45-micrometer, visible-blue, wavelengths requires a camera on the satellite with a 75-centimeter-diameter lens. The same resolution from a SkySite™ Platform at 30 kilometers above the earth only requires a 3.3-centimeter-diameter lens. Also since the SkySite™ Platform speed over ground is about 14 meters per second, instead of a LEO satellite's 7 km per second, there is the ability to loiter above a target and wait for clouds to move or observe changes in the target area. Since there is virtually no turbulence at 30,000 meters altitude, the payload is gravity gradient stabilized.

Tactical Platform for Military / Homeland Defense. The beauty of our lightweight SkySite™ Platform is the ease of launch. With a tank of helium or hydrogen, one person can launch a SkySite™ Platform in a matter of minutes. This shows great promise for forward-deployed tactical units to launch at will a variety of payloads to support their efforts. The range of applications includes communications relay for troops and sensors, real-time downlink of imagery, signals intelligence, and chaff release. While balloon payloads are generally assumed to be lightweight, Table 2 shows conservative maximum payload weights based on the altitude, and balloon size. Balloons are able to carry aloft many payloads comparable to typical UAV packages at a very small fraction of the cost. Though not providing the versatility of an Unmanned Air Vehicle (UAV) in terms of controlled lateral movement, the SkySite™ Platform does provide flexible control of its altitude. This enables users to control lateral movement based on wind direction at various altitudes. Since SkySite™ Platforms inherently have the radar cross-section of a bird they have natural stealth. Since they fly at altitudes higher than any aircraft and most missiles can reach, they are less susceptible to being shot down than UAVs and other airborne platforms, and are much less costly if they are lost. In fact, they can be treated as expendable from the time of launch. Unlike satellites, which follow predictable orbits likely known to the enemy, SkySite™ platforms can be launched so as to fly over a target of interest at anytime.

One particular area getting a lot of attention in military applications, and branching out into the non-military world, is ad hoc networks, also known as mesh networks. Floating routers on SkySite™ Platforms would enable a rapid network configuration in hostile areas, providing all forms of traffic currently reliant on high-value platforms or not available at all. SkySite™ Technology blends nicely with the dynamic nature of ad hoc networks, and the ease with which a new node can be sent aloft ensures reliable coverage in a changing battlefield environment. With ad hoc networks likely to play a pivotal role in wireless Internet services, this application of SkySite™ Technology tracks well with Space Data's future plans for including broadband capabilities among our various balloon-borne services.

Even the low-data-rate messaging payload ready for commercial deployment this summer has several potential military and homeland defense applications. Soldiers or forest fire fighters could be given commercial two-way pagers for communications. Text messaging is inherently robust in traffic peaks. In fact, all members of Congress now carry text messaging devices because only dedicated text messaging networks continued to work during peak traffic of the September 11th terrorist attacks. These devices weigh less than 100 grams, last a month on one AA battery, and cost $100. The group page capability allows entire groups to be messaged at the same time to warn of incoming SCUD missiles or shifts in the direction of a forest fire. Small $10 receive-only boards could be built into land mines. This would allow mines over a wide area to be disabled after hostilities have ended.

Signals Intelligence. The advantage of easy launch-on-demand may have a unique ability for signal intelligence. The commercial messaging payload shown in Figure 14, is a digital software radio with two DSPs synched to GPS timing. This allows a constellation of SkySite™ Platforms to listen to desired frequency bands. As the location of each SkySite™ Platform is known by GPS within a few meters and the platforms share the same time standard, it is possible to passively geolocate signals of interest to determine their point of origin.

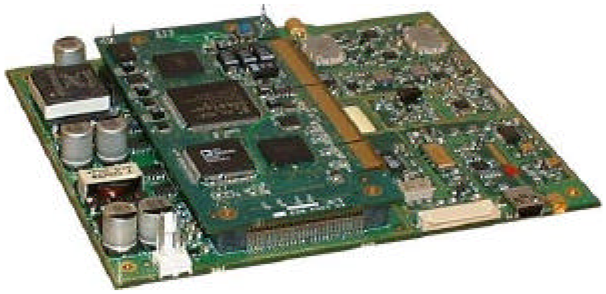

Figure 14: Commercial wireless messaging SkySite™ Transceiver Assembly.

Bi-static Radar. Clusters of SkySite™ Platforms can be operated cooperatively to perform the function of a single large satellite. This concept is the basis behind the Air Force Research Laboratory, Space Vehicles Directorate's TechSat 21 program.[17] In this program the Air Force is testing the concept of flying a swarm of satellites and collaborating the small apertures of these satellites to act as one large array. This allows virtually unlimited size apertures to be synthesized. Equation 2, which was examined earlier for optical resolution of a system, also applies to radar. However with radar the wavelengths are a million times longer than the wavelength of light. Thus, one must either settle for much lower resolution from radar or create a way to make a very large aperture. One potential application that could be tested in the near-term with the commercial SkySite™ Messaging Payload is a bistatic radar. Most radars work by transmitting a pulse of radio energy and then listening to the return echo. SkySite™ Platforms are power limited and thus unlikely to be able to create enough energy to illuminate a target on the ground. However, the commercial SkySite™ Messaging Payload is a highly capable receiver in the commercial paging bands at 900 MHz. In these bands towers transmit at power levels up to 3500 watts and all transmissions are time synched with GPS. By monitoring the synchronization pulse emitting from these towers a cluster of SkySite™ Platforms could sample the leading edge and the return energy reflected off the ground clutter. This high-resolution digital snapshot from each SkySite™ Platform could then be transmitted to the ground where a computer can correlate the signals. The resolution of the synthetic aperture radar image is determined by the diameter of the entire cluster of SkySite™ Platforms. As it is relatively inexpensive to launch a cluster of SkySite™ Platforms that together are hundreds of miles in diameter, fairly high-resolution synthetic aperture radar images are possible.

Conclusion

SkySite™ Systems take advantage of the rapid decreasing cost and size of microelectronics to provide low-cost, scalable, and flexible approaches to many traditional space system missions. Space Data Corporation has developed the SkySite™ Technology initially for two-way wireless text messaging and plans to initiate commercial service this summer.

Authors

Jerry Knoblach is a co-founder of Space Data Corporation and its Chairman and CEO. Mr. Knoblach earned an MBA degree from Harvard University, a master's degree in electrical engineering from the University of Minnesota, and a bachelor's degree in mechanical engineering from the Massachusetts Institute of Technology. Mr. Knoblach is a licensed professional engineer and has been awarded two patents in the area of composite materials.

From 1996 to 1998, Mr. Knoblach was a program manager at CrossLink, Inc., a wireless communications equipment company. At CrossLink, he led an effort to develop a commercial communications system for the space shuttle, using the Inmarsat satellite system that provides connections to the Internet, voice and fax capabilities and the use of commercial hardware to enable rapid development. The system first flew in June 1998. From 1992 to 1997, Mr. Knoblach was a manager of business development and a program manager for Orbital Sciences Corporation ("Orbital"). From 1995 to 1997, he was responsible for marketing radiosondes and satellite ground stations. In 1996, he played a key role in winning a contract with the US Air Force to develop and produce the next generation radiosondes using GPS technology. From 1994 to 1995, Mr. Knoblach served as a program manager at Orbital's subsidiary, Magellan Systems Corporation, where he led the effort to develop the first hand-held, personal communicator for use with the Orbcomm satellite network. Mr. Knoblach managed a marketing effort that won a contract to develop a GPS guided missile during 1992 and 1994. Prior to Orbital, Mr. Knoblach spent five years at FMC Corporation in Minneapolis, Minnesota, designing guns and missile launchers for the US Navy and Air Force.

Jerry Quenneville is Vice President of Engineering at Space Data Corporation. Prior to joining Space Data, he spent over 20 years in the US Air Force in various engineering, research, and technical program management capacities in support of the US intelligence community. His responsibilities included the engineering, development, and deployment of intelligence systems, high reliability space and terrestrial communications systems, modeling and simulation systems, and special-purpose digital and software-based applications. These capabilities ranged in size from small rapid prototypes to multimillion dollar worldwide systems, serving traditional intelligence missions and advanced battlefield support. Mr. Quenneville earned a Master's degree from California Institute of Technology and a Bachelor's degree from the University of Massachusetts at Amherst, both in Electrical Engineering.

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