Keysight Technologies
Utilizing Commercial Best Practices for Success in NewSpace

White Paper

Abstract

History has seen many different industries make the transition from low volume and high cost to high volume and low cost. Ensuring product quality through such a transition is very difficult. When combined with the additional requirements imposed by space this transition becomes even more challenging. The space industry is in the midst of dramatic change. NewSpace is driving disruption that we haven't seen since the original space race in the 1960's. Business models are completely new. This paper will describe the challenges that these unique business models put on electronic design and test strategies and processes. We will present ways to enable much higher volume with much lower cost while maintaining high quality.

KEYSIGHT TECHNOLOGIES

Introduction

It is a very exciting time in the space business. The industry is energized and changing rapidly. The term NewSpace has emerged to describe these changes.

> ***What is NewSpace?***
> *NewSpace is an emerging global industry of private companies and entrepreneurs who primarily target commercial customers, are backed by risk capital seeking a return, and profit from innovative products or services developed in or for space.*[1]

A huge number of companies are entering the space business. When NewSpace Global started in 2011 they were tracking about 125 companies. They are now tracking well over 800, about 700 of which are privately held.

Most people have seen the press coverage of SpaceX, OneWeb, Google and Facebook and their "change the world scale" plans for space. These companies will certainly drive disruptive change on a massive scale, but they are far from the only ones. Hundreds of other companies are getting into space with an amazingly wide variety of business models and mission types -from communications to earth imaging to weather forecasting to mining asteroids to interplanetary human existence.

But the NewSpace movement is not limited to new entrants. Many established traditional space companies and organizations are adapting and working to understand how best they can take advantage of the opportunities that all of this excitement presents. Alliances have been, and continue to be, formed between new entrants and established space players.

In many ways, NewSpace is not a new industry so much as it is a major disruptive force in the space industry as a whole.

Electronic design and test are integral elements of spacecraft development. As NewSpace drives change in the space industry, the philosophies, strategies, processes and requirements associated with electronic design, development, production, test and measurement change as well. This paper will describe NewSpace, contrast it with traditional space, and explore the implications for electronic design and test.

1. "What is NewSpace?", NewSpace Global, LLC., last accessed March 5, 2015, **www.newspaceglobal.com**

Industry Trends and Characteristics of NewSpace

This is not your father's space industry. NewSpace is a combination of Silicon Valley startup mentality meets space visionaries meets a good measure of traditional space experience.

Several business characteristics distinguish NewSpace from traditional space:

- Primary objective is to make a profit from an investment
- Commercial business and funding models
- Willingness to take risk

As these companies are primarily targeting commercial enterprise, commercial business principles apply. Accordingly, most NewSpace endeavors construct business models based on a level of investment, on-going cost structure, and revenue stream that results in a profitable outcome. Funding in NewSpace is coming from sources that historically have not been a part of the space industry. The past several years have seen substantial venture capital investment in NewSpace endeavors. Crowd funding and angel investment are also playing a significant role.

One of the most telling attributes of NewSpace is risk tolerance. Historically, with traditional space ventures risk is considered bad. As such, tremendous amounts of time, effort and expense are employed in an attempt to eliminate risk. Risk profiles in NewSpace are far different from those of traditional space. NewSpace companies are not foolhardy, but they understand that risk is something to be considered, assessed and managed. The level of risk tolerance varies significantly across companies and business models. The key is that risk is part of the business model to be managed - not some evil thing that must be eliminated at all cost.

Many market and technical trends are enabling, or are associated with, NewSpace:

- Rapid growth in the number of relatively low cost satellites
- Numerous deployments of satellite constellations
- Satellites with short orbital life expectancies
- Prolific use of commercial off-the-shelf (COTS) components
- Lower launch costs
- More frequent launches
- Increasing global competition
- Joint developments
- Hosted payloads

A critical attribute of the NewSpace movement is less expensive access to space. Lower launch costs are integral to many NewSpace business models. For example, a company considering a satellite constellation may say, "If we can build N satellites for $X and launch them for $Y, our business model closes and we can make a viable business."

Ride-sharing has emerged as a relatively low cost launch method for small satellites. While ridesharing is relatively inexpensive it does subject the secondary payload to the priorities of the primary. If the primary payload schedule slips, the secondary also slips. Conversely, the primary is going to go when it goes. If the secondary is not ready it misses its chance. Further launch cost reductions are in the works. SpaceX and others are championing the use of reusable boosters. At the time of this writing, SpaceX had twice attempted landing the main stage booster of a Falcon 9 on a floating barge – close, but not quite. It seems a certainty that they will eventually be successful. Consistent reusability has the potential to reduce launch cost by an order of magnitude or more. Another trend focused on reducing launch cost, while eliminating the ride along issues, is dedicated small launch vehicles. A number of companies are developing launch vehicles specifically designed to deliver smaller payloads at lower price and higher launch frequency.

NewSpace has driven the emergence of low cost spacecraft, including the rapid growth of relatively low cost small satellites (SmallSats). These range from extremely small (e.g. PocketQube at 150 g) to 500 kg. This is a wide range leading to further classification. Table 1 shows the most common sub-classification of SmallSats. Specifically, the CubeSat has become a very popular standardized form-factor in the NanoSat class. Business models vary significantly across the classes.

Table 1: Small satellite sub-classifications

Sub-Classification	Mass Range (kg)
MiniSat	100 - 500
MicroSat	10 - 100
NanoSat	1 - 10
PicoSat	0.1 - 1
FemtoSat	< 0.1

While the trend is certainly to lower the cost of satellites, an opposing trend is that engineers are coming up with new, exciting and more complex things for these satellites to do. So, in many cases, while costs need to go down, complexity is going up.

In addition to smaller size, the number of satellites associated with many NewSpace business models or missions is much larger than traditional space norms. Many SmallSat businesses are planning to deploy large constellations – 10's, 100's even 1000's - of satellites. The majority of these are in low earth orbit (LEO). Intended mission lifetimes are much shorter than has historically been the case where 15 years of life was common for most traditional satellites. For NewSpace, lifetimes of 2 to 5 years is becoming common and others are even less. These business models are based on the on-going presence of the constellation, so in order to sustain the business, the constellation needs to be regularly replenished. The large number of companies deploying constellations, the size of the constellations, and relatively short orbital lifetimes are combining to drive dramatic volume growth in SmallSat production. Industry estimates range from 2500 to 4000 new SmallSats in orbit between now and the end of this decade.

As many of these spacecraft are designed for shorter orbital lifetime and intended for LEO operation where the radiation environment is relatively mild, the designs typically can be less robust than traditional satellites, particularly as compared to a geosynchronous satellite intended for a 15 year lifetime. This drives another key enabler of cost reduction for NewSpace - the use of commercial off-the-shelf (COTS) parts. Historically, the space industry used predominantly (often exclusively) space-qualified parts. COTS parts intended for terrestrial industries are far less expensive, more available, and typically further advanced in performance than space qualified parts. Of course, the use of COTS parts also introduces risk. This is a key area where NewSpace calculates an acceptable level of risk to reduce cost and leverage advanced technologies.

NewSpace developers generally do some level of qualification of COTS parts consistent with their mission, risk profile and business model. This effectively makes a COTS part "somewhat space qualified". Similarly, automotive and industrial parts are widely used, as they are subject to a more rigorous qualification process than consumer electronics, but they are still far less expensive than space qualified.

Agile development processes have been widely utilized in the software industry. Agile has proven to be an effective approach enabling rapid time-to-market processes. However, traditional space development is pretty much the antithesis of agile. A number of NewSpace companies are employing agile methods to spacecraft development – develop, release, learn and iterate on very short cycles – months rather than years. Several companies have extended agile methods into orbit – launching prototype capability, learning from it on-orbit, and feeding learnings back into the next revision. Agile provides the opportunity to test elements of functionality and technology earlier than may be practical otherwise. For any given NewSpace mission and business model, agile methods may or may not be the best approach. It is certainly something to consider.

Business Challenges

The elements above provide great opportunity, but significant business challenges exist:

- Effective risk management
- Time-to-market and schedule pressure
- Expense and cost management
- Delivering volume in an industry not accustomed to it
- Need to continuously innovate
- Finding, attracting and keeping technical talent

With risk tolerance, comes the requirement for an effective approach to risk management. A critical aspect of any commercial enterprise is understanding, assessment, analysis and management of risk including mitigation and contingency plans. NewSpace companies need to establish what risks they are willing and are not willing to take.

Schedule and time-to-market pressure are ever-present in the commercial world. This drives a shorter development lifecycle and creates pressure to deploy product sooner. In NewSpace, schedule pressure is not only driven by the market and the desire to beat the competition, but may also be driven by a specific launch window, or the need to get a new group of satellites in orbit to replace those that are approaching end-of-life in order to not disrupt the revenue stream.

Rockets and satellites have traditionally been a very low volume business with a very high per unit cost. Many NewSpace business models are driving volumes several orders of magnitude higher than traditional norms. The challenge is to be able to effectively scale and still maintain quality. Business models are built based on certain cost estimates – typically ranges of cost estimates. In order for the business model to work, cost targets must be achieved. This drives the need to control development, product, and deployment costs across the enterprise.

The consumer electronics industry has certainly shown that in order to sustain a strong business model companies must continuously innovate. One of the great things about relatively short orbital lifetimes is that they provide the opportunity to update technology much more often than has traditionally been the case in space. However, it provides that same advantage to competitors, so companies must continue to innovate in order to keep your business model compelling and to remain competitive. All of this innovation must be delivered while controlling cost and maintaining schedule. Further, in most cases the task is fundamentally difficult. Space is hard. This is rocket science. Adding commercial business goals compounds the challenge.

Overcoming these challenges and delivering continuous innovation requires a lot of high quality technical talent. Both experienced technical professionals and new graduates are in very high demand. Attracting and keeping good engineers and technicians is a big challenge across all segments of high technology. In many cases this will dictate geographic choices and often impacts key business decisions.

Electronic Design and Test Strategy Considerations

Electronic design and test are integral elements of spacecraft development and deployment. As NewSpace drives change, the philosophies, strategies, processes and requirements associated with electronic design, development, production, test and measurement change as well. In particular, the volume, cost and schedule challenges of NewSpace drive a different approach than traditional space. Utilization of best practices from the commercial electronics sector, efficiently aligned with the unique needs of space, is essential to a successful and sustainable NewSpace business model.

The basic construct of the electronic product development cycle is quite common across industries:

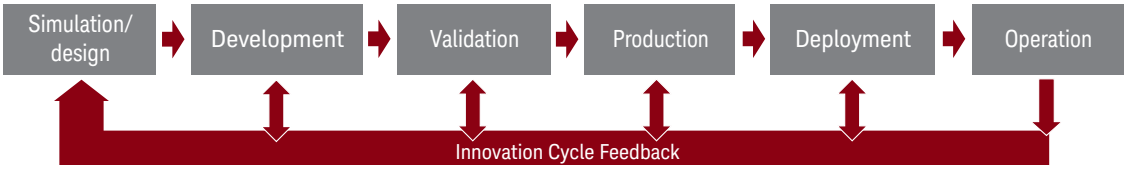

Figure 1: Typical electronic product development cycle.

Key elements that distinguish different industries are the definition of each stage, the criteria for moving between them and the rigor with which the process is followed. In very low volume conditions like traditional space the lines between development, validation and production are often somewhat blurred. Conversely, with the volumes of many NewSpace businesses the lines need to be more defined in order to scale volume efficiently. As volumes increase it is particularly important to have clearly defined criteria for release to production. Debugging design problems in production impacts cost and schedule and slows down the primary function of production, which is to ship products. Additionally, different industries and companies have different approaches to how much they utilize innovation cycle feedback. This loop is integral to meeting the business challenge of continuous innovation. Simulation and measurement tools to support this feedback mechanism are key.

In order to achieve business success it's crucial to define specific design and test strategies and processes consistent with your business model and business realities. Business considerations drive design and test objectives which dictate the attributes of the design and test process reuired to meet those objectives and ultimately drive a specific implementation approach.

Figure 2: Flow for design and test process definition.

Many of these items may seem obvious while others are not as clear. Even some of the more obvious ones can get overlooked in a challenging schedule-and cost-constrained environment. Here we'll highlight and expand on several of the less obvious items and some that often get overlooked.

Business considerations

Many factors impact the success of a given business model. Some of the key considerations relevant to the design and test strategy are:

- Functional, performance and physical requirements
- Timeline and market window
- Cost requirements
- Volume and throughput requirements
- Risk profile
- Future plans
- Core versus context

Documenting and tracking requirements may seem obvious, but oftentimes in very schedule-driven developments, this critical element gets overlooked or pushed aside. This typically creates confusion between the designers and test developers and often results in schedule slippage.

A critical part of achieving business success is having a design and test process that aligns with your risk profile. Historically, the design, validation and test approach employed in the space industry was very different from that of the commercial electronics industry. Far and away the highest priority of the process in traditional space was to beat the risk down as much as possible, often at the expense of schedule and cost – test everything, and test it a lot. Almost by definition, NewSpace is willing to accept some level of risk. A key element of the test strategy is to define what risks are and are not acceptable – establish and document a risk profile. For example, perhaps you are willing to accept a 5% failure rate over a 2 year period, and plan to mitigate this risk in your system design. A detailed assessment of risk will help drive the test strategy and process. The test process targeted at a 5% failure rate is quite different from one that targets 1% or 20%. Of course, one that targets 1% would achieve the 5% target, but may exceed cost and schedule targets.

It's important to consider your future plans as part of the process definition. Assess short, medium and long-term goals. Do you plan to grow in volume? Do you plan to expand your product portfolio or increase complexity? If you expect your needs to change in the future, it's important to make choices now that enable you to adapt and upgrade over time.

A second key element that is not necessarily obvious, and is often overlooked in process definition, is the concept of core versus context. Core is that content which your organization is uniquely capable of executing better, faster or cheaper than an outside source. Context is everything else that is necessary for business success, but is not part of the core. The more you are able to focus on your core, the higher likelihood you will have for a successful and sustainable process. Your process may be best served by outsourcing context items to enable more focus on core. For example, equipment calibration and maintenance is essential for business success in electronic design and production, but for many companies it is not part of their core. What is core and what is context may change over time. It is important to review core versus context regularly in order to maintain focus on key differentiators as business conditions change.

Process objectives, attributes and implementation

The objectives, attributes and specific implementation approach of a design and test process are very tightly linked. As such, they often get blurred together. It is critical that the attributes align with the objectives and that the implementation aligns with the attributes and achieves the objectives. Table 2 lists primary objectives, attributes and implementation elements.

Objectives	Attributes	Implementation Elements
– Predictable performance from proposal through operation – Identify and eliminate problems as early in process as possible – Identify and understand weak points/ potential points of failure early – Sustainable quality – Continuous process improvement – Minimize test system setup time – Maximize yield – Maximize uptime – Ensure throughput targets	– Effective modeling of product and system performance – Design for manufacturability, test and cost (DFx) – Consistent, common and repeatable measurement science throughout the process – Data consistency to support trending and prediction – Clear criteria for “production ready” – Robust validation testing – Efficient production testing – Minimize use of hand-crafted products – Clear delineation between forward and reverse flow – Minimize probability of operator error	– Model and measure early to understand weak points – Start testing early on - breadboards and early prototypes – Detailed and inclusive DFx reviews – Utilize methods for accelerated testing to ferret out weak points quickly and effectively – Focus test resource on areas of greatest concern – Test what needs to be tested – not what doesn’t – Test enough – don’t test too much – Eliminate rework in the forward flow – Failed units move immediately to reverse flow – Automation – Parallel test – Outsourcing

No single implementation approach will fit every NewSpace business model. However, focus on the items discussed above will provide the context to make the best implementation choices for a given business model. All of the items in Table 2 have some level of impact across the business model. However, each has primary impact in one of three broad categories – design robustness, volume enablement and cost management.

Design robustness

Effective and accurate modeling is necessary in order to be confident that a given product or system concept will meet the requirements and align with the business model. The simulation tools used should support margin analysis and the ability to incorporate measured data. Improperly managed margins can add significant cost and risk to a program. If margins are too tight, unnecessary costs are pushed down to subsystems and components. If margins are too loose, they could stack up unfavorably, leading to poor system performance or failure. Simulation and models help properly manage margins for optimum performance and cost tradeoffs. Simulation and test data consistency throughout the process also enables trending and improved prediction over time. It’s key that the measurement science employed at each stage is repeatable and consistent with other stages.

Modeling will also provide early insight into the problem areas and potential weak points in the design. Problems caught early in the process are far less costly – both in terms of money and schedule – than problems found late in the process. Start testing early. Build breadboards and early prototype assemblies, particularly of the highest concern parts of the design, and perform rigorous testing on them. Hardware-in-the-loop integrated with your simulation software and models increases fidelity of your system simulations. This enables higher confidence in advance of first “turn on” of the system as to whether the pieces are going to work or not.

Highly accelerated life testing (HALT) or highly accelerated stress testing (HAST) can be a very effective approach for early detection of design problems and infant mortality. The level and formality of HALT/HAST that is used should be consistent with the product and business model. For example, in order to test the lifetime quality of electrical connections, a combined thermal and vibration environmental test can be done to add additional stresses. This may lead to the detection of fatigue or fracture that would normally take years to manifest itself as a failure. By doing a rapid test that might constitute some percentage of the lifetime number of cycles expected, you can catch issues without the need for extremely long test cycles.

Volume enablement

Design for manufacturability, design for integration, design for test, design for quality, and design for cost are essential for a profitable business model. These DFx techniques are tightly related, and it is critical to consider and review these elements early in the process. The reviews should include all of the key stakeholders – R&D, test engineering, production and quality. Early feedback on DFx issues will pay off in production with improved throughput and yield.

It is crucial to have clear and aligned criteria for "production ready". Rigorous and broad testing and debugging of the design should be focused in development and validation phases. As you move into production, focus on the areas of greatest concern. Consider not testing or only sample testing the areas that have little cause for concern. For example, if modeling and early testing has shown sensitivity to low temperature, but not high temperature, consider mainly testing at low. However, it is critical to test at a level consistent with the risk profile and potential failure modes.

In the production test process it is critical to have clear distinction between forward flow and reverse flow. If a unit fails in forward flow, it must be removed and transferred into reverse flow. This is critical to achieving throughput objectives. When failed units remain in forward flow for debugging, they create a bottleneck slowing, or even stopping, product shipments. Process automation is a powerful tool in a volume test process. Automation brings significant advantages:

- Reduced test system setup and measurement time
- Reduced risk of test operator error
- Utilization – maximize usage of capital equipment
- Improved yields, reduced rework and re-test
- Reduced human attended test time

However, automation will typically incur additional up-front expense and initial setup time. The level of automation that is sensible will be dictated by several factors. Assess and determine what level of automation best delivers the target metrics defined above.

Parallel testing can take several forms – multiple channels, multiple measurement types, multiple units under test (UUTs), etc. The primary objective is to ensure throughput and asset utilization objectives are achieved.

Cost management

Outsourcing is widely used in the commercial electronics industry. As discussed earlier, core versus context is an important consideration. For those things that are deemed to be context outsourcing may be a viable alternative. It can provide advantages in process efficiency and overall cost. Additionally, outsourcing can help address the challenge of attracting technical talent, as contract resources may be available where permanent hires are not. Outsourcing is certainly not to be taken lightly, but it is something that should be considered as part of an effective business model.

When aligning the design and test process with the business model, one of the primary factors to understand is how they impact cost. Primary contributors to cost include:

- Yield
- Test time and throughput
- Utilization
- Equipment cost

When computing the equipment cost it is essential to take a total cost of ownership (TCO) view of the process and the associated value delivered. Oftentimes the equipment cost is viewed only in terms of the initial purchase. TCO is key to understanding the real cost and associated impact on the business model. TCO is defined to be the total cost to own and operate a piece of equipment over its useful life. Keysight has developed a TCO model for the industry comprised of the two core elements of capital expenses (acquisition costs) and operating expenses. Refer to reference [1] for detailed information on TCO.

Keysight is the Electronic Design and Test Partner of Choice

As you define your electronic design and test process, work with a partner that can support your business as well as technical needs. Keysight offers the broadest portfolio of electronic design and test services and products to assist you from early design though production, deployment, operation and maintenance. Keysight has been the leading provider of electronic design and test solutions to the space industry throughout its history – initially as Hewlett -Packard and then as Agilent, and we continue that tradition now as Keysight. Throughout that time we have also been the leading provider of electronic design and test solutions to the commercial electronics industry. Keysight has a strong history of successfully applying lessons learned in the commercial electronics industry to the Aerospace industry. We are committed to delivering electronic design and test products, solutions and services to meet the changing needs of the industries we serve. We can help you leverage best practices from the commercial electronics industry to address the unique challenges of NewSpace.

We can help you map your business objectives to your design and test processes and tools. Our products and services can support you through the entire product lifecycle from early design & simulation through production to operations, maintenance and refresh. Through our process analysis services we share our experience and expertise to help you take advantages of the best practices of commercial electronics in the unique world of NewSpace. Our services include:

- Process analysis
- Calibration and repair
- Asset management
- Custom applications engineering
- Test system and process design and implementation
- Resident professional program – Keysight experts embedded with your team
- In-depth technical training

Our product portfolio is the broadest in the electronic design and test industry. This enables you to get the solution that best aligns with your business model.

Our EEsof electronic design automation software portfolio spans from low-level circuit design with industry leading Advanced Design System (ADS) to complex system level modeling with SystemVue. We are the leading provider of electronic measurement instruments and software in nearly every significant category. We also offer a broad array of application specific test systems and automation solutions.

Keysight is best known for our high performance bench-top box instruments. While we are very proud of that, we offer products over a very wide range of price-performance: from basic products to fit very tight budgets, to the highest performance to meet the most difficult measurement challenges. We also have a broad portfolio of hand-held instruments including the Field Fox hand-held combination network and spectrum analyzer. Modular instrumentation is also a major focus area for us with a rapidly expanding portfolio in PXI, AXIe and USB form factors. Keysight's software portfolio offers solutions that support our broad hardware offering with applications across industries and throughout the product lifecycle.

Our industry-leading measurement science is employed across our portfolio delivering measurement and data consistency throughout the design and test process regardless of product choice. For example, the same measurement algorithms are used in our basic class CXA spectrum analyzer as in our highest performance class UXA. Those same algorithms are also employed in our PXI vector signal analyzers, 89601B vector signal analysis software and SystemVue system level design software.

Keysight is committed to enabling NewSpace business models including cost management. We offer a broad array of tools to enhance affordability and deliver superior total cost of ownership. Comprehensive upgrade capability and trade-in programs enable your Keysight solution to grow as your needs change.

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Conclusion

NewSpace is creating tremendous excitement in the space industry. New companies are entering the industry and traditional companies are adapting. Many completely new business models are emerging. This paper has described the challenges that these unique business models put on electronic design and test strategies and processes and offered considerations, insights and approaches to help overcome these challenges. Ensuring quality while dramatically increasing volume and reducing cost is very difficult. It is going to take a strong balance of commercial electronics and traditional space industries, combined with completely new discoveries, to realize the promise of NewSpace. Keysight is ready to help you realize the promise of your NewSpace business model by bringing together the best of commercial and aerospace electronic design and test.

References:

[1] “The Real Total Cost of Ownership of Your Test Equipment”, Bill Lycette and Duane Lowenstein, Keysight Whitepaper, p/n 5990-6642EN.

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