Firefly Alpha - A Mass Produced Small Launch Vehicle for the New Space Era

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ABSTRACT

The space industry is experiencing a revolution in the growth of small satellites, and yet adequate solutions to launch these new generations of small satellites are not yet available. With a focus on low cost and launching when the customer needs to launch, Firefly Space Systems have developed a new type of small satellite launch vehicle which has been designed with low cost and mass production as primary drivers. From materials selection, through technology selection to production processes and approaches, everything about the Firefly Alpha (the first Firefly Vehicle) has been designed for high cadence, efficient, low cost production.

INTRODUCTION

Firefly Space Systems develops launch vehicles to service the small satellite market. The first of these vehicles, Alpha, is scheduled for launch in March 2018. With the rapid growth of the small satellite market, and customer negotiations underway, Firefly expects to quickly ramp Alpha launch cadence to 52 launches per year, or a launch per week.

Launch vehicles are traditionally not optimized for mass production. The rapid growth of the small satellite market enables a paradigm shift towards a market that will require rapid, low-cost production of launch vehicles.

EVOLUTION AND GROWTH OF THE SMALL SATELLITE MARKET

The small satellite market is generally accepted to be the segment of the satellite market which is growing at the fastest rate. From 2009 until 2015, the market growth for small satellites has been strong, exhibiting a growth of over 28% per year. Forecasted growth rates can vary significantly but all forecasts are predicting a significant amount of growth in the next 5-10 years, resulting in an increasing demand for launch opportunities for small satellites. Firefly's view of the expected growth in demand for launch opportunities that could be serviced by Alpha-class launch vehicles, is summarized in Figure 1.

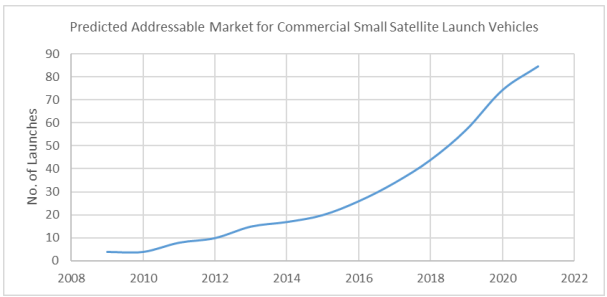

Figure 1: Forecasted requirement for small satellite launches for vehicles in the Alpha class

Firefly expects to address a number of segments within the small satellite market, including:

- The launch of single small satellites of mass of up to ~400kg (mass dependent on the destination orbit and inclination),
- The launch of constellations of micro and nanosatellites, with individual masses from ~3-50 kg,
- The replenishment of single satellites in large constellations, including impending 'mega' constellations

PAYLOAD DELIVERY CAPABILITIES

The bulk of the small satellite market utilizes high inclination orbits, with Sun Synchronous Orbits (SSO, ~98^{o} inclination) being favoured by the majority of Earth Observation (EO) satellite customers, and polar (0^{o}) orbits typically being specified by many of the emerging LEO-based communications constellations. With the above market segments in mind, the Firefly Alpha vehicle has been sized to deliver a payload of 200kg in to a 500km Sun Synchronous Orbit (SSO). Payloads of up to 400kg can be delivered in to equatorial, low altitude (~300km) orbits.

A number of payload accommodation scenarios are available, with a range of fairing sizes and common payload interfaces and adapters. These payload configurations include:

- Single satellite (primary passenger) only
- Prime Passenger plus auxiliary payloads (cubesats)
- Cluster configurations featuring multiple cubesats.

Accommodation within Firefly Alpha's fairing are illustrated in Figure 2, which also shows a typical launch configuration featuring a primary small satellite passenger and a number of 3U cubesats.

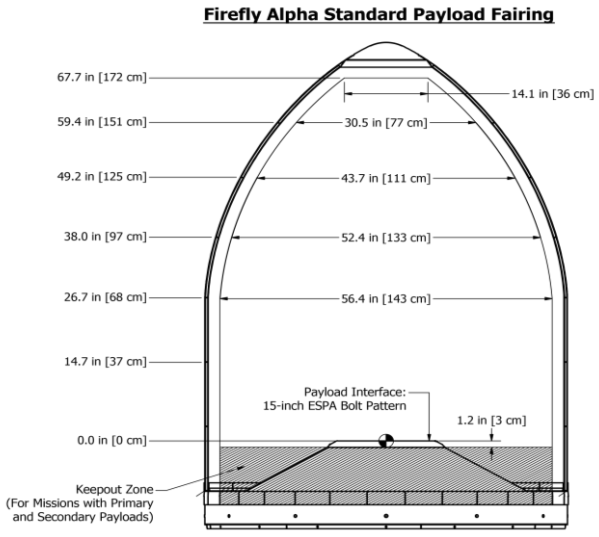

Figure 2: Firefly Alpha Payload Volume

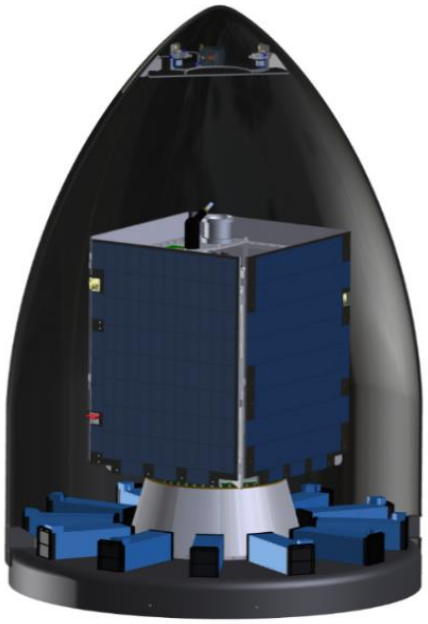

Figure 3: Firefly Payload Accommodation

FIREFLY VEHICLE OVERVIEW

Firefly Alpha is an all-composite, pressure-fed, two-stage launch vehicle capable of delivering 200kg to a 500km sun synchronous orbit (SSO). The first stage employs an Aerospike engine, with the core engine elements on the first stage shared by the second stage. An overview of the vehicle is illustrated in Figure 4.

The Firefly Alpha vehicle has been developed with the following main characteristics:

Propellant: LOx/hydrocarbon propellant combinations are the most mature, simplest to handle, and are highly available. Therefore, Firefly Alpha utilises Rocket Propellant-1 (RP-1, Kerosene). The "kernel" of the Alpha propulsion system is a relatively small, conventional combustor for ease of manufacturing.

Engine cycle: Firefly Alpha features an all pressure-fed design, without turbomachinery, to improve reliability and reduce the number of moving parts on the vehicle.

Staging: Two stages, at a minimum, are required to achieve orbit with LOx/hydrocarbon propellants. While adding additional stages would increase the payload mass fraction, reliability and simplicity factors drove the choice to make Alpha a two stage vehicle.

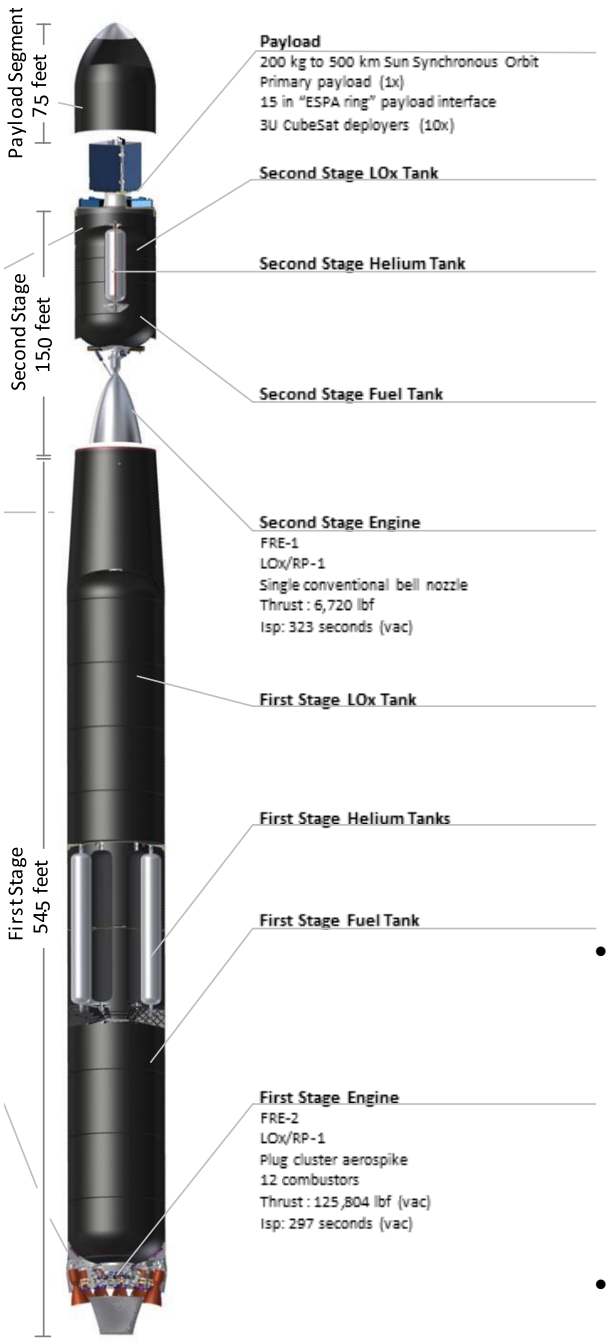

Figure 4: Firefly Space Systems Alpha Launch Vehicle

THE FIREFLY APPROACH

Firefly applies a cost-driven and pragmatic approach to developing launch vehicles to serve the growing small satellite market. With potential market growth in mind, it is likely that launch frequencies up to one launch per week could be required by the market. Firefly, therefore, is developing vehicles which can support such a launch cadence.

There are a number of key elements within Firefly's development approach which enable this frequency target to be achieved, including:

- Design for Production and Assembly
- Nature & (co)location of facilities
- Production Processes
- Supply Chain approach and management

Design for Production and Assembly

Design for production is a key aspect for Firefly, and is being applied to all of the key subsystems as follows:

- Propulsion
  - Standard, non-exotic and readily available materials are specified/selected
  - All parts are designed for low-cost manufacture using established and understood processes.
- Structures
  - Specification and utilisation of common and readily available, 'non-exotic' materials.
  - Use of pre-qualified materials to minimize qualification testing.
  - Materials specified are cost-effective with a supply chain in place which can provide the capacity and volumes required to support high-volume and regular production runs.
- Tanks
  - Use of innovative but readily available composite materials.
  - Implementing a liner-less design enabled via proprietary materials and techniques.
  - Use of simple and well established construction techniques
- Avionics
  - Use of Surface Mount Technology (SMT) processes throughout
    - Automated component 'pick and place'
    - Automated soldering (reflow)
    - Automated inspection of assemblies by X-ray.

A key aspect in the vehicle development is the colocation of designers, Design for Manufacture (DFM) engineers, and manufacturing personnel in Firefly's offices and facilities. This teamwork ensures that all components, assemblies, and tooling is designed with efficiency and cost-effective manufacturability as drivers. Assessment and concurrence by DFM is required for all design reviews and release of engineering packages.

Another key element is design for assembly. Small launch vehicles, of the size/class of Firefly Alpha, tend to be comprised of smaller pieces and subassemblies versus their larger counterparts. This factor has been exploited by Firefly, and has resulted in many practical advantages and cost savings relating to vehicle assembly. For instance, the nature and size of the engines which make up the first and second stages enable engine cores to simply machined using standard (and not bespoke) milling machines, and the resulting engines can be hand carried, negating the need for large cranes and complex handling and transportation requirements associated with larger vehicles and assemblies.

Facilities

Efficient and effective testing is a key part of the vehicle production cycle. Firefly's main assembly and test facilities are located less than 25 miles from the main headquarters and office buildings in Austin, Texas. The production and test facilities (including engine test stands) are collocated with the main production and assembly buildings. This can be seen in Figure 5.

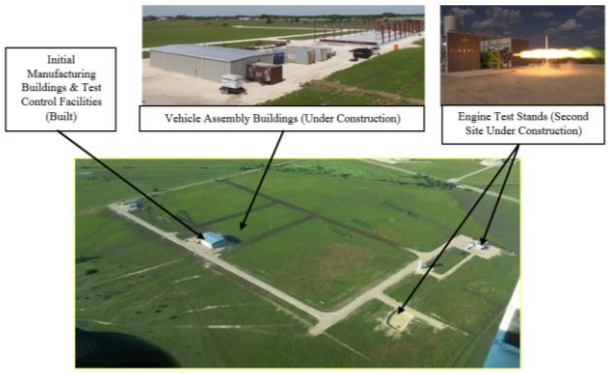

Figure 5: Firefly Production and Test Site

This colocation of functions, coupled with the proximity to the main headquarters and offices, enables and ensures the most cost and time efficient production and test flows, also allowing engineers based at the main headquarters to easily attend testing activities when required, whether planned or unplanned, minimizing the probability of delays in production caused by the lack of key personnel in attendance. Firefly's test site is extremely large in terms of its footprint and available area, with significant potential for expansion in terms of additional vehicle assembly buildings. This is another key forward thinking and planning factor in ensuring that required vehicle production rates are achievable in the long term.

Supply Chain and Make/Buy Approach

Production of early Alpha vehicles is being implemented through the use of a significant supply chain, with some elements contracted out to established suppliers and others addressed internally. A manufacturing and production roadmap is in place to bring key production processes in-house, to provide vertically integrated production operations.

Production and Manufacturing Process Evolution

Early Firefly vehicles will be produced primarily with traditional and well-established/qualified methods and processes, and significant touch labour. With the need and objective of increasing vehicle production rate to 1 per week, increasingly modern and automated production and manufacturing methods will be developed, qualified, and introduced into production. Techniques and technologies such as Additive Layer Manufacturing (ALM, more commonly known as '3D printing'), automated composites manufacture, and automated assembly and testing techniques are currently on the roadmap for future, long term vehicle production. As stated previously, the avionics for the Alpha vehicle will be manufactured utilizing established automated manufacture processes. In addition, an automated test setup will be implemented for the avionics systems early in vehicle production. With these production process improvements in mind, all manufacturing and production tooling is being designed and built for high volume multiples, in order to ensure future proofing of these high value investment items.

Production Team

Firefly's production team is made up individuals who have significant experience in the launch vehicle domain, and therefore the relevant experience in the production team is at a very high level. The many lessons learned from these experiences are all being taken account of in the definition of Firefly's launch vehicle production philosophy, planning and detailed processes and procedures.

IMPLEMENTATION OF DESIGN UPGRADES

Upgrades and improvements to the Firefly's launch vehicles are expected. In order to implement upgrades in the most efficient and robust/error free manner, a 'block upgrade' approach is being implemented by Firefly, whereby small improvements and upgrades across multiple areas/subsystems are grouped together in to single, consolidated upgrade blocks. Compared to an incremental upgrade approach where upgrades and improvements are implemented one at a time, whenever they become available, the block upgrade approach is considered to offer more reliability and assuredness in terms of configuration management, traceability and non-conformance/error management.

DEVELOPMENT PROGRESS

A robust development and qualification plan for the Alpha vehicle has been put in place and is being followed. Key technology development and demonstration has been the focus of the early development phase, with later phases focussing on the demonstration of system functional blocks and assemblies. Development of the Firefly Alpha vehicle is well underway with many key development milestones having been met in 2015 and early 2016, including

- Qualification of key manufacturing materials and processes required for the production of the main propellant and oxidiser tanks
- Manufacture and testing (hot firing) of the main engine core, which features on both stages of the vehicle (see Figure 6).
- Manufacture of core avionics modules in an extremely compact and lightweight format (see Figure 7)

Figure 6: Firefly Main Engine Core Hot Fire Testing

Figure 7: Firefly Avionics Card

CONCLUSIONS

Firefly Space Systems are developing small launch vehicles for the rapidly growing small satellite market. A key aspect of the development approach being followed is design for rapid and low-cost production, which are required to support a forecasted launch frequency of up to 52 launches/year. This paper has summarized the key aspects of that approach, showing how Firefly Space Systems are developing designs and approaches to enable the mass production of small launch vehicles

REFERENCES

[1] "Firefly – a New Generation of Low Cost Small Satellite Launch Vehicles designed to serve the rapidly growing Small Satellite Market", *Tom Markusic, PhD, Shey Sabripour, PJ King, Andy Bradford, IAC, 2015, Jerusalem, Israel*

[2]Firefly Payload User Guide, Version 1, July 2015

[3]First Rocket Engine Test a Success for Firefly Space Systems (Press Release), September 10th 2015