# Mass Manufacturing of Small Satellites, Gearing up for the Henry Ford Moment

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## ABSTRACT

The trend towards (mega) constellations among small satellites is unbroken. Instead of yesterday's satellites that were often not much more than prototypes the new space business models require a nothing less than a change of how satellites are being produced. The situation is thus not unlike those of the car industry in the early 20th century. Berlin Space Technologies (Germany), a global leader in small satellite systems has teamed up with Azista Industries (India) to build a factory to mass manufacture small satellites in the range of 50-150kg in India. The Joint venture is currently building a pioneer facility that has an annual production capability of up to 250 satellites. Due to the highly parallelized approach the facility can easily be extended to cover annual production rates of more than 1000 satellites a year. The factory is placed in Ahmedabad close to ISROs Space Application Centre / SAC (3.5 miles) and offers 50,000 square feet floor space. The brick works have been finished in 2018 and currently the interior furnishing of the clean rooms is underway. The first satellite will be assembled in the factory in late 2019. After that the production capability will be increased to reach the target production rate end of 2021.

## INTRODUCTION

In every industry there is a moment when the products go from individual prototype to serial production. Most notable this happened in the car industry between 1910-1920. In the early 20th century cars were largely bespoke devices built by specialized companies for a small crowd of (rich) people. Given the small number of cars produced the number of car manufacturers as well as the number of involved workers per car were unnecessarily large.

At this point in time there were hundreds of car manufacturers globally and 250 car manufacturers in the United States of America alone. As a European example, the German car manufacturer Daimler manufactured fewer than 1000 cars using almost 2000 workers.

**Figure 1: Assembly Belt Production [A]**

A decade the numbers of cars had skyrocketed, and the numbers of car manufacturers had dwindled. In 1929, less than 44 car manufacturers had survived with 80% being accumulated by the big three.

**Table 1: Model-T Production & Price [1]**

| Year | Production Rate | Price Per Unit |
|---|---|---|
| 1910 | 19,050 | $23,000 |
| 1911 | 34,858 | $18,285 |
| 1912 | 68,773 | $15,318 |
| 1913 | 170,211 | $13,309 |
| 1914 | 202,667 | $11,006 |
| 1915 | 308,162 | $9,659 |
| 1916 | 501,462 | $7,943 |
| 1917 | 735,020 | $9,778 |
| 1918 | 664,076 | $8,329 |
| 1919 | 498,342 | $7,226 |
| 1920 | 941,042 | $4,940 |

Note: prices are converted to USD 2019

Within a decade the car had been transformed: from a luxury good for the lucky few to a business necessity for the great multitude. This disruption proved very profitable for those who implemented it. The small satellite industry today is facing similar challenges and thus valuable lessons can be learned.

## SMALL SATELLITE MASS MANUFACTURING

### *Towards the Henry Ford Moment for Small Satellites*

Today, a century later, the Space Industry of Old is not unlike the car industry before Ford. As of now most satellites in the range of 50-150kg are still largely bespoke devices built by specialist companies.

With less than 100 satellites annually in that range (outside mega constellations) and more than 50 manufacturers globally the global average per company is about 1-2 devices per year. Only very few companies including heavy weights like SSTL produce more than 5 satellites per year. This was ok when traditional space was relying on a small number of large single (or few) space crafts per mission that were owned by an equally small number of large operators.

Since beginning of the 21th century two enabling factors have happened. First the introduction of the Cubesat by Stanford University and California Polytechnic State University in 1999 [6] allowed a much larger number of players to build their own missions. While in the first steps the Cubesat revolution were carried out with 1U sized satellites mainly by universities and non-traditional actors the lower entry barriers ultimately allowed an ever-growing number of commercial actors to enter the market. Those new actors have then grown their satellites and started thinking outside the box. As a result, todays constellations see a trend from Nano- satellites towards larger satellites.

### *Motivation – Constellations all around!*

Fast forward to 2019, according to NSR, the number of satellites in planned and upcoming constellations is larger than 25,000 [3]. The overwhelming majority of these satellites will be in the Communication mega constellations which dominantly make use of large micro or small mini satellites.


**Figure 2: Satellite (Mega) Constellations [C]**

There is thus a significant market pull for the implementation of serial production for small satellites especially in the range of 50-150kg.

### *Target Figures of the Industry – from cars to space*

While 25,000 satellites seem to be an overwhelming number for today's industry one must consider that with a lifetime of 5 years this would only require a sustained production rate of 5000 satellites per year. To put this into perspective: while a Model 3 is significantly more complex than a small satellite, the GigaFactory is churning out 5000 cars per week [2] alone.

**Figure 3: From Cars to Space [B]**

In addition, not all those constellations that are announced will make it to the launch site and not all of those that are getting launched be sustainable.

Based on the authors own research a sustained global production requirement of 1000 satellites per year seems significantly more likely. This is in line with recent publications Euroconsult [4] estimates a demand of 7000 satellites over the next decade reaching a peak of 850 satellites per year by 2027.

### *How many satellite factories do we need?*

Considering that even the OneWeb facility in Florida will have a capacity of more than 1000 satellites annually that means that the required number of factories will be very low. In fact, if not for the customers (mega constellation operators) desire to avoid dependencies for a single source – one satellite factory globally would do.

A valuable lesson is thus to look what happened to the car industry. Even there one manufacturer technically would have been able to scoop up the market. In the end it was a group of three that held 80% of it. If not for government interventions, similar things are likely to happen in the space industry.

### *The Satellite Factory of your Dreams!*

Thinking about future satellite factories the public eye envisions robot filled assembly lines not unlike the automotive industry. However, this is highly unlikely for the space industry.

If one would apply the same techniques from the car industry for satellites even a global annual production rate of 5000 satellites would only require around 200[1] workers or 40 workers for 1000 satellites respectively.

### *Key Requirements for a satellite factory*

Other participants of the industry do agree with the authors observation; the OneWeb satellite factory only makes use of a single robotic arm per assembly line. This robotic arm is used not to speed up production but to place the battery in an otherwise awkward position for a human worker.

Instead of going all in trying to apply means of automation that for the space industry are neither required nor sustainable Berlin Space Technologies thus established more reasonable goals for the automation of the small satellite industry:

- Reduce built time by 100x
- Reduce cost by 10x
- Increase production rate by 100x

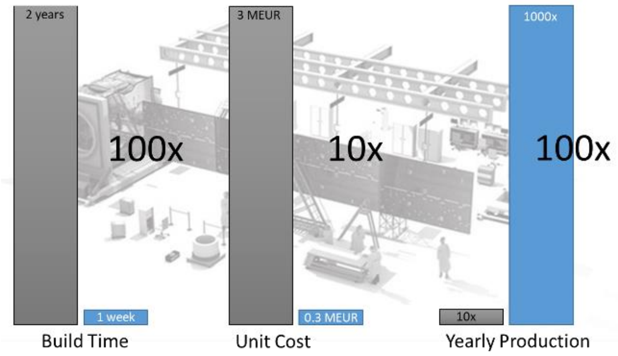


**Figure 4: Targets for Mass Manufacturing**

By meeting these numbers, it is possible to transform a company that produces micro satellites today to fulfil the current market demand of 1000 satellites per year.

[1] A company like Toyota produces about 9 Million cars with a work force of 360,000 people. Hence on average a worker builds 25 cars per year.

### *State of the art – and improvements thereof*

Traditionally a small satellite is built as a single device. It requires on average a team of 25 people for the duration of 2 years to design, built and test it. Considering a labor cost of $150k per person and year this leads to an average price of $7.5M if it is built from scratch. This can be reduced by using standardized components (low NRE) and limiting your design choices, the result however will still be a satellite that costs several million USD. Interestingly this thought experiments shows that it the system cost of a satellite (or any technical device) is mainly influenced by the accumulated labor cost (amount of work hour and the cost per person) of all hands involved.

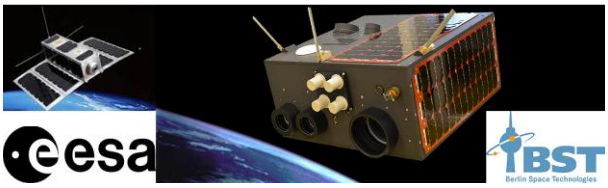


**Figure 5: Two Satellites – Different Size, Same Cost**

The amount of labor required in turn is mainly dependent on system complexity and not as public believe has it by the actual mass of the satellite.

It is thus important to make all steps of the process simpler, meaning ultimate need is to make the amount of time the production team spends on each device.

The authors have analyzed in detail how to improve the traditional way how to build satellites [5] and have documented the following means to improve:

Modular Platform:
In a modular platform your design choices are limited. While Cubesats restrict not only the size and form of the electronics but also the outside of the satellite [6] other industry platforms such as SSTL X-50 [7] have electronic modules that can be used for satellites ranging from 50kg to 250kg. A similar approach has been chosen by BST where the in-house avionics can be used for satellites ranging from 30kg to 150kg.

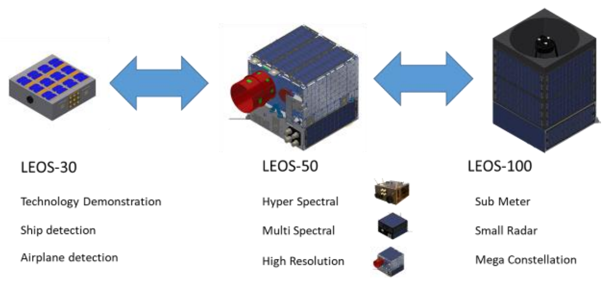


**Figure 6: Common Avionics Across Platforms**

Industrialized Production:

In todays space industry many things are still hand made. Taking a cue from industrial production and testing greatly helps improving the situation. Among the first to suggest such an implementation was SSTL with their SSTL X-50 platform [8]. In short, the utilization of rapid manufacturing from the electronics industry, adapted to the qualification standards of the space industry. This includes automatic PCB manufacturing, the use of pick and place machines as well as automatic test rigs. Over the last 5 years BST has developed in-house a full suit of these technologies and is applying them in the satellite factory.

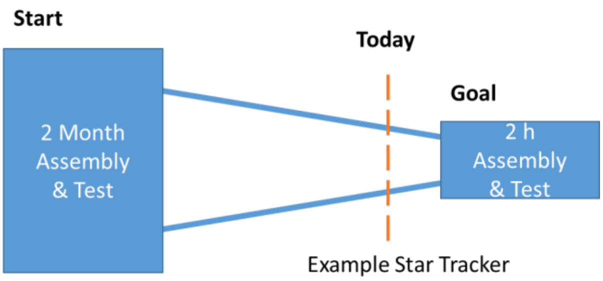


**Figure 7: Reduction of equipment production time**

Rapid Assembly and Testing:

Main driver for all space projects is the test spent in assembly and testing. This is true both on system as well as on subsystem level. While a fully manual test campaign can take month to finish BST has proven that subsystems can be assembled and tested in a matter of hours while on system level projects such as the PNP satellite funded by the Office of Responsive Space (ORS) [9] or TUBSAT of TU Berlin [10] have shown that without applying boundless new technologies it is possible to finish the integration and testing of satellite in a matter of days then the 6 month that is the industry standard.

BST itself has already shown to be able to conduct a full AIT for a satellite in 3 weeks and is currently working to reach a target figure of less than 1 week.

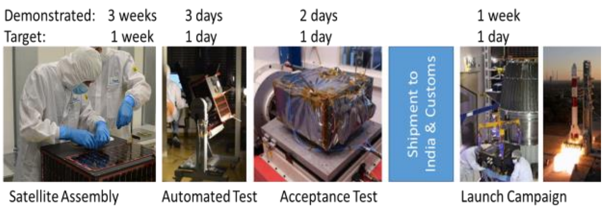


**Figure 8: BST Rapid Assembly and Testing**

## ABOUT AZISTA BST AEROSPACE

The satellite factory of Azista BST Aerospace has been in the making since early 2017. It is being built by: Azista Industries and Berlin Space Technologies

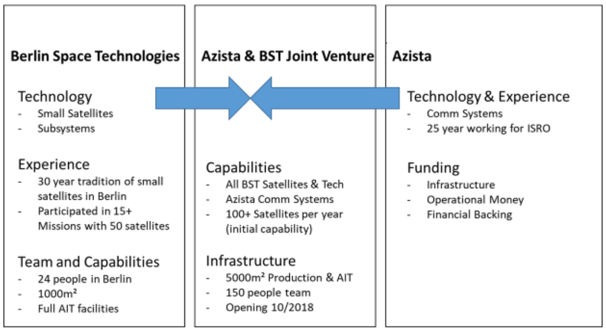


**Figure 9: Azista and BST Joint Venture**

Azista BST Aerospace focusses on small satellite systems with launch mass between 50-150kg. These satellites are based on the proven LEOS platform by Berlin Space Technologies.

| | Parameter | LEOS-30 (based on iBOSS - iBLOCK) | LEOS-50 | LEOS-100 |
|---|---|---|---|---|
| | Payload Volume | 360x360x260mm³ 36 liter | 530x530x340mm³ 96 liter | 530x530x620mm³ 174 liter |
| kg | Payload Mass | 10-15kg | 15-30kg | 30-70kg |
| | Payload Power For 9:30h 505km SSO @ 100% Nadir Pointing + 20min/day transmit | 100W peak for 20min per orbit 20W av. for 100min per orbit | 150W peak for 20min per orbit 30W av. for 100min per orbit | 300W peak for 20min per orbit 75W av. for 100min per orbit |
| | Platform Design Life | 2 years | 5 years | 5 years |
| | Experience | iBOSS Demonstrator (planned for 2019) | KR1 (2015), KR1B (Delivered) NExSat & Lagari (Delivery 2019) | 10x LEOS-100 for India (Delivery 2020/21) |

**Figure 10: Capabilities of the LEOS platform**

The company has access to all IP of their respective parent companies. Unique across industries Azista BST Aerospace can manufacture every satellite subsystem in-house (except propulsion).

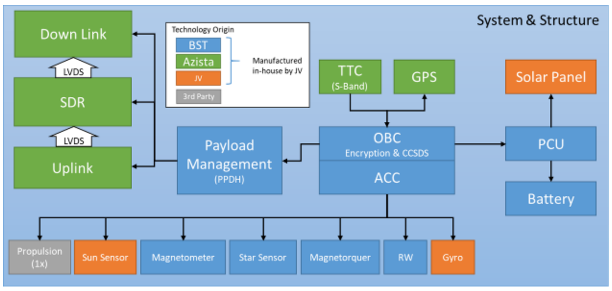


**Figure 11: All Subsystems Manufactured in-house**

This vertical integration is an advantage when it comes to cost effective manufacturing of small satellites. Since all subsystems utilize the same hardware components as well as software libraries system verification can be built across the entire platform.

***About Berlin Space Technologies***

Berlin Space Technologies (BST) is a global leader in Small Satellites Systems. BST is building of the 30-year tradition of small satellites in Berlin. It has contributed to more than 50 satellite missions and manufactured several satellite systems in house.

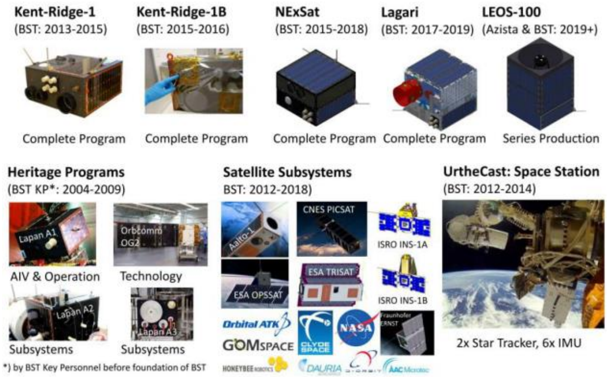


**Figure 12: BST Mission Heritage**

BST has built up an extensive research and development lab that offers more than 10,000 sqft. of clean rooms, labs and offices.

**Figure 13: BST Headquarter in Berlin (Germany)**

BST is a leader in lean manufacturing of small satellites. Its team is currently assembling 3 satellites in parallel and is building subsystems hardware for several 10s of satellites.

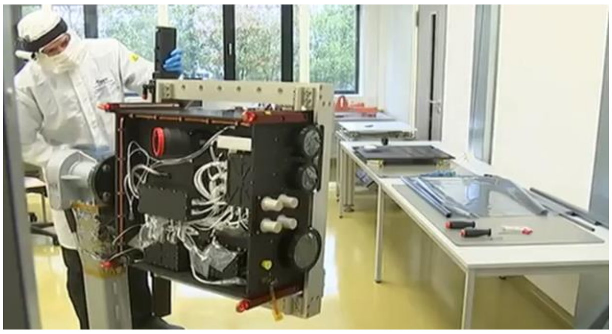

**Figure 14: BST Headquarter in Berlin (Germany)**

***About Azista Aerospace***

Azista Industries (Hyderabad, India) via its subsidiary Azista Aerospace (Ahmedabad, India) has more than 25 years of experience in the space domain. It has contributed subsystems to more than 25 satellite missions mainly in the field of communication systems for geostationary as well as low earth orbit satellites.

**Figure 15: Azista Aerospace in Ahmedabad (India)**

Azista Aerospace currently operates 27,500 sqft. of clean rooms, labs and offices.

**Figure 16: Azista Aerospace Clean Room**

Its staff of currently 80 people is dedicated to mass manufacturing of both satellites hardware (mainly for ISROs GEO satellites) as well as satellite ground systems (distributed data collection stations).

**Figure 17: HiRel Manufacturing and QA**

## THE SATELLITE FACTORY

The satellite factory (Unit 01) is located in the outskirts of Ahmedabad India. A short car ride from the Azista Aerospace subsystem facility. The facility is jointly operated by Azista BST Aerospace as well as Azista Aerospace.


**Figure 18: Azista BST Satellite Factory**

### *Key Figures and Design*

The facility offers 55,000 sqft. of clean room and AIT lab space over two main floors. The facility is designed to have a nominal capacity of 250+ satellites per year.

**Figure 19: Impression of the Interior Size**

The joint venture mainly makes use of the first floor while Azista Aerospace uses the ground floor. The TVAC chambers, the shakers and the radio test chamber which are also located on the ground floor are used by the JV and Azista Aerospace Jointly. At the outside of the facility several auxiliary buildings for additional test facilities as well as the liquid N2 storage are located.

Centre piece of the factory are 5 parallel clean rooms around which the subsystem manufacturing labs are located. The hardware enters production at the 12h position and follows the production clockwise. After assembly the satellites are then released for testing at the 12h position of the building.

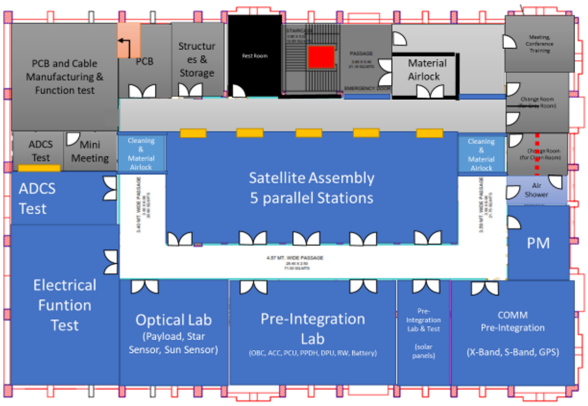


**Figure 20: Factory Layout**

Based on a satellite assembly time of 1 week. The 5 parallel clean rooms will insure a nominal production rate of 250+ devices per year. The next iteration of the factory (Unit 02) has 5x the capacity of the current factory. 20 parallel clean rooms will enable a production capability of 1000+ devices.

### *Status*

The satellite factory is in the last stages of completion. The brick works have been finished in mid-2018. Currently the interior (labs & clean rooms) is under construction. The work will be finished by end 2019. The facilities in Ahmedabad are currently receiving the required equipment including:

<u>Electronics Manufacturing Equipment</u>

The Unit 01 will be equipped with the ability to manufacture 1 satellite subsystem set per day. This sufficient to achieve the desired 250+ satellites per year capability.

**Figure 21: Pick and Place 16k parts/hour**

AIT Test Facilities

The Unit 01 will be equipped with full AIT facilities. These facilities will be used to test both subsystems as well as full satellite systems according to the highest standards.

- ISO-8 and ISO-7 Clean Rooms
- Optical Test Facility
- Anechoic Test Chamber 5x5x5m
- ADCS Test Facility
- 3x Shaker with up to 60kN
- 3x TVAC Chamber with 1.5m diameter

**Figure 22: 30KN Shaker at Unit 01**

***Production Test Run***

The team is currently been training in the Azista Facility in Ahmedabad. There small production runs are tested under realistic scenarios. Recently a production batch of 100 ground station transceivers has been produced. The entire production run from contract start to delivery was done in less than 3 weeks.

**Figure 23: 100x transceiver in 3 weeks**

Further production runs with up to 800 devices (satellite controlled remote weather stations) have been implemented in equally short time. This shows that the team is ready for larger production runs once the factory opens end of 2019.

**Figure 24: 800x satellite-controlled weather stations**

***The First Satellite(s)***

Azista BST Aerospace is currently gearing up for the production of the first prototype satellites. The first satellite (FastRunner) will be finished until mid-2020 to be ready for launch end 2020. Further 10 satellites will be built for Azista BST aerospace internal consumption as well as customers in the time frame until end of 2020. The nominal capacity of the factory will be reached end of 2021.

***Future Capacity - Ramping up production***

The factory in its present form is mainly meant as a pioneer facility. It has a nominal capacity to manufacture 250+ satellites per year including all subsystems. Azista BST is currently planning a follow factory (Unit 02) will located on 10 acres plot nearby. This extension will allow to ramp up production past 1000+ satellites annually.

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