Commercial Space Transportation

QUARTERLY LAUNCH REPORT

Special Report:

Trends in Satellite Manufacturing: Changing How the Commercial Space Transportation Industry Does Business

1st Quarter 1999

United States Department of Transportation • Federal Aviation Administration
Associate Administrator for Commercial Space Transportation
800 Independence Ave. SW Room 331
Washington, D.C. 20591

Special Report

Trends in Satellite Manufacturing: Changing How the Commercial Space Transportation Industry Does Business

INTRODUCTION

In recent years, the commercial sector of the satellite industry has seen unprecedented growth. An expanding base of satellite applications and satellite services has increased the demand for satellites and has brought about changes in almost every aspect of the commercial space industry. In particular, the increasing demands placed on current and future communications satellites have had major effects on satellite design and production.

Manufacturers are building larger satellites to provide the greater capacity required by geosynchronous (GEO) communication satellite operators. Competitive pressures are also pushing manufacturers to reduce cycle times on GEO satellite orders. As a result, larger satellites are being built in a shorter period of time than ever before. At the same time, an entirely new market for smaller, low-earth orbit (LEO) satellites has arisen. New mobile satellite services require large fleets of smaller satellites to LEO which in turn require manufacturers to build dozens of identical spacecraft in a short period of time. To accomplish this, manufacturers have moved away from extensive customization and craft production methods and towards an assembly line style of production. Part of this change involves the use of standardized satellite designs and more commercial off-the-shelf parts from outside suppliers. Another aspect of this change is the emergence of new production facilities designed, from their inception, for mass production.

These differing satellite production requirements have given rise to a two-tiered manufacturing industry. One tier builds large GEO satellites and large numbers of smaller satellites for LEO constellations, while a smaller segment of the industry uses the availability of off-the-shelf components to construct customized, individual satellites. Although there is some overlap between these groups, they are largely distinct: one serves large commercial customers, and the other serves smaller science, education, and technology development customers.

The launch industry has also been affected by the growing demand for satellite services. The need to launch larger GEO payloads and to launch multiple LEO satellites on a single launch vehicle has increased the demand for space transportation services worldwide. Launch service providers have moved to develop vehicles capable of carrying heavier payloads to GEO, as well as new hardware capable of deploying multiple satellites to LEO. Moreover, the need to launch and replenish LEO constellations has increased the demand for medium and intermediate vehicles. Reusable launch vehicle (RLV) operators have also targeted the LEO constellation replenishment market.

This report examines the effects that the growth in LEO and GEO satellite services has had on satellite manufacturers, service providers, and on the launch industry. It will also examine some of the implications that these changes hold for the future of the commercial space industry.

LEO SATELLITE MANUFACTURING

The unique characteristics of LEO constellations have, in part, driven new manufacturing practices. Because of their lower orbits, LEO satellites have smaller signal footprints and are in view for only short periods of time from a particular spot on the ground. Consequently, LEO constellations require the construction of dozens of satellites for complete global coverage (Table 1). In order to meet the demand for the satellites required by LEO constellations, manufacturers have adopted mass-production assembly line techniques to speed and streamline the manufacturing process. Although small details may differ between manufacturers, there is a basic underlying similarity. Satellites are mounted on wheeled dollies and moved from production station to production station. Work teams at each station are assigned to specific tasks.[1]

The efficiency of the assembly line method relies, in part, on the standardization of the manufacturing process. Instead of using custom-built satellite buses and components, manufacturers are now able to use a standard bus structure and integrate off-the-shelf payload hardware. Motorola, discussed below, uses this practice to build the Iridium satellites. In the manufacture of the Globalstar satellites, for example, Alenia uses pre-assembled subsystem kits.[2] By using proven technology and relying on the suppliers' quality control processes, satellite manufacturers are able to eliminate a significant amount of time previously spent testing and inspecting individual parts. Additionally, manufacturers have reduced the number of completed satellites being tested. At Alenia, only every other Globalstar is tested, which can be expected to drop to every fourth satellite as production progresses and quality remains high.[3] Consequently, manufacturers have been able to reduce completion time to a

Table 1: Selected Current and Proposed LEO Systems

System	# Satellites in System (# On-Orbit Spares)	# Currently in Orbit	Manufacturer	Launch Vehicle	Beginning of Service
Iridium	66 (6)	79 (+5 inactive)	Motorola, Lockheed Martin	Long March, Delta, Proton	November 1998
Globalstar	48 (8)	8	Space Systems/ Loral, Alcatel, Alenia	Delta, Soyuz, Zenit	1999
Orbcomm	28 (8)	28	Orbital Sciences Corp.	Pegasus, Taurus	November 1998
Skybridge	60 (4)	0	Skybridge LLC	Not selected	2002
Teledesic	288*	0	Motorola, Matra Marconi	Not selected	2003

*The most recent plans call for a 288-satellite constellation (original plans called for a 980-satellite constellation) but this number may change as details of the new constellation plans are worked out.

[1] "Faster and Cheaper Ways to Build Satellites," *Interavia Business and Technology*, March 1997.

[2] Ibid.

[3] Ibid.

matter of days. Teledesic, for example, recently reported that their planned mass-production methods will allow the completion of a satellite every two days.[4]

Faster production and the purchase of standardized components allows manufacturers – and their customers – to save money in the manufacturing process. As a result, LEO constellation designers have been able to trade off the possibility of launch failure or on-orbit failure against the ease of replacement brought by a faster and cheaper manufacturing process. If a satellite fails once on orbit, it can be quickly and cheaply replaced by an on-orbit spare or another low-cost ground spare from the same factory. Teledesic, for example, has announced that rather than paying insurance premiums on their constellation, they will simply construct more back-up satellites.

Iridium provides one of the most publicized examples of the new manufacturing processes. The Iridium bus is first built by Lockheed Martin's Sanders subsidiary in Nashua, New Hampshire. According to officials at the plant, their assembly line procedures allowed them to produce a record of fourteen buses in one month. The communications payload is then built and integrated into the bus at the Motorola Satellite Communications facility in Chandler, Arizona.

Motorola's Chandler facility is also a classic assembly-line operation, operational 24 hours a day, seven days a week, and is organized into three phases. In the first two, workers wire circuit boards and components and integrate the boards onto the satellite bus. The final process couples assembly line procedures with a work-station environment: satellites are wheeled from station to station, rather than forcing workers to move their operations from satellite to satellite. The payload is also designed so that a defective module can be replaced within 60 seconds, rather than the three weeks it may take for a conventional satellite.[5] Once the satellite bus is received at the Chandler facility, Motorola can integrate the components and complete the satellite within 28 days.[6] The facility is able to produce a new satellite every four days.

The new mass production methods have allowed the construction of dozens of satellites for LEO constellations. As a result the number of LEO satellites built per year has risen in the last few years and will likely continue to do so for the next five years. This has implications for the launch industry, as will be discussed below.

EFFECT ON THE LAUNCH INDUSTRY

The growing number of LEO payloads awaiting launch opportunities signal increased opportunities for launch service providers (Figure 1). The current demand for medium and intermediate launch vehicle services has been driven, in part, by the growth in the LEO market.[7] In order to capitalize on this market, launch providers have also developed dispenser systems for deploying multiple satellites to LEO. These systems have been successfully used aboard Delta, Proton, and Long March vehicles, and are planed for use on Soyuz, Ariane, and Zenit. These dispensers allow the deployment of multiple payloads within a single launch.

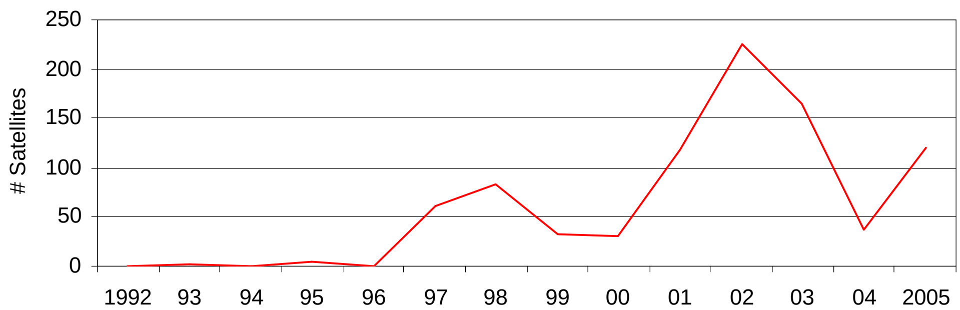
[4] "Motorola Plans Speedy Teledesic Assembly Line," *Space News* 12/14/98, p. 2.

[5] "Faster and Cheaper Ways to Build Satellites," *Interavia Business and Technology*, March 1997.

[6] "Motorola Plans Speedy Teledesic Assembly Line," *Space News* 12/14/98, p. 2.

[7] "New Satellite Uses Spur Space Boom," *Aviation Week & Space Technology*, 6/3/96.

Figure 1: Commercial LEO Satellites Launched/ Scheduled for Launch 1992-2005



Source: STAR Database, 1998 LEO Commercial Market Baseline Projections (FAA/AST May 1998)

Standardized satellite designs also allow greater flexibility in choosing a launch vehicle. Because these small satellites fit inside a number of fairing types, manufacturers and operators are able to choose from among several launch vehicle sizes in order to meet tight schedules or overcome unforeseen problems. This is precisely what has happened to Loral's Globalstar constellation. The September 9, 1998 failure of a Zenit vehicle (which carried twelve Globalstar satellites onboard) threatened the plans to begin service in 1999. Within two months, however, the company was able to arrange additional launches on board Soyuz and Delta vehicles, thus reducing the delay to Globalstar's schedule.[8]

Additionally, the emerging LEO launch market has encouraged a host of entrepreneurial firms to develop reusable launch vehicles (RLVs) in order to capitalize on the demand for LEO constellation maintenance and replenishment. RLVs such as the Kistler K-1, Rotary Rocket's Roton-C, Kelly Space and Technology's Astroliner, Pioneer Rocketplane's Pathfinder, and Space Access' SA-1 plan to begin service within the next few years. These RLV start-up companies, and others, intend to enter the launch market by offering inexpensive frequent flights to LEO, including replenishment flights to replace aging or inactive constellation satellites.[9]

GEO Satellite Manufacturing

The increase in demand for C-band, Ku-band, and Ka-band GEO satellite services has affected the hardware being integrated into satellites, as well as their manufacturing methods. In response to the market, satellite manufacturers and their suppliers are developing new technologies to achieve higher performance while attempting to keep launch mass as low as possible.

As GEO satellites have become more powerful, a number of specific applications have been developed, including VSAT networks, direct-to-home broadcasting, internet backbone, and regional mobile telecommunications services. In turn, this brings a particular set of technical requirements to the manufacturing process. These new satellites use smaller ground terminals than their previous counterparts, requiring greater signal strength and higher on-board power. In order to maximize the

[8] "Globalstar Shifts Launchers After Failure of Zenit," *Space News*, 9/14/98 p. 1.

[9] *Reusable Launch Vehicle Programs and Concepts*, FAA/AST, January 1998.

use of orbital slots while at the same time maximize revenue, new GEO satellites must also carry additional transponders and antennas in order to meet the increasing traffic requirements, as well as more on-board fuel for station-keeping to extend mission life. Despite the entry of a number of new technologies that decrease satellite structural mass -- such as more efficient transponders, gallium arsenide solar cells, better thermal radiators to dissipate the extra heat caused by higher power, and ion propulsion instead of standard fuel -- the mass of new GEO satellites is steadily increasing (see Figures 2 and 3). As discussed below, this trend also has further implications for the launch industry.

The time required for construction has also changed in response to market demands. Originally, GEO satellite manufacturing was highly specialized: each satellite was largely one-of-a-kind with customized systems, painstakingly assembled and tested, taking three years to build. In order to meet the growing demand for GEO satellites, manufacturers have had to decrease construction time. Like LEO manufacturing, this has been accomplished through several methods. Both Hughes and Lockheed Martin have introduced assembly-line procedures at their new satellite factories in El Segundo and Sunnyvale, respectively. GEO satellite manufacturers further reduce construction times by relying on standard components from suppliers, rather than relying on customized systems. Based on the assumption that proven designs and suppliers' quality control processes ensure component reliability, this eliminates the need for time-consuming testing of subsystems. While not as short as LEO times, GEO satellite manufacturing has been reduced from three years to around 18 months, with some firms targeting one year or less. The recent launch of Russian broadcast company Media Most's Bonum-1 provides a timely example of the increased demand for both satellite services and quick cycle time. On October 22, 1997, Media Most signed a contract with Hughes Space and Communications to provide Bonum-1, a HS-376 satellite for direct-to-home services over western Russia. The contract marked the first time that a satellite for a private Russian company would be built by a U.S. manufacturer. According to the Bonum-1 subsidiary of Media Most, Hughes won the contract because it promised to manufacture and deliver the satellite on-orbit within sixteen months.[10] Russian manufacturer NPO Prikladnoi Mekhaniki, on the other hand, might have taken 36 months. The now-operational satellite was successfully launched on a Delta 2 on November 22, 1998, only thirteen months after the contract was signed, and three months earlier than expected.

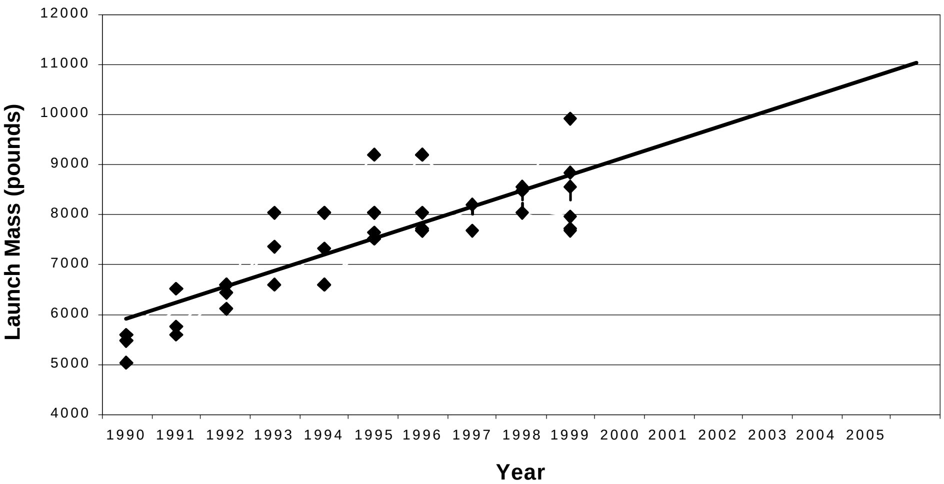
Effects on the Launch Industry

In order to meet the increased launch demand for large GEO satellites (Figure 4), several companies have developed vehicles capable of taking heavier satellites to geosynchronous transfer orbit (GTO) (Table 2). Many of these new vehicles have also required the construction of new construction and launch facilities.[11]

These new vehicles include the new Atlas 3B which will offer a GTO capacity of 9,920 pounds, compared to the 8,196 pounds offered by the largest Atlas variant in service, the Atlas 2AS. The future Delta 4 and Atlas EELV launch vehicles will

[10] "U.S. Firms Hope Bonum-1 Opens Russia's Doors," *Space News*, Dec. 6, 1998, p. 7.
[11] *Commercial Space Transportation Quarterly Launch Report* FAA/AST, 4th Quarter 1998.

Figure 2: GEO Satellite Mass Trends 1990-2005



Note: Heaviest 25 percent of commercial GEO satellites launched 1990-1998, with projected payloads for 1999. Trend line represents linear fit of average payload mass in sample for each year, extended through 2005. The COMSTAC mission model for 1998 projects that one third to one half of 2002-2005 payloads will be heavy (>9,000 lb.). Source: STAR database, COMSTAC Report (May 1998).

Figure 3: Launch Mass of Satellite Models Currently In Production

Note: Date following mass range indicates year of first launch. Source: STAR database.

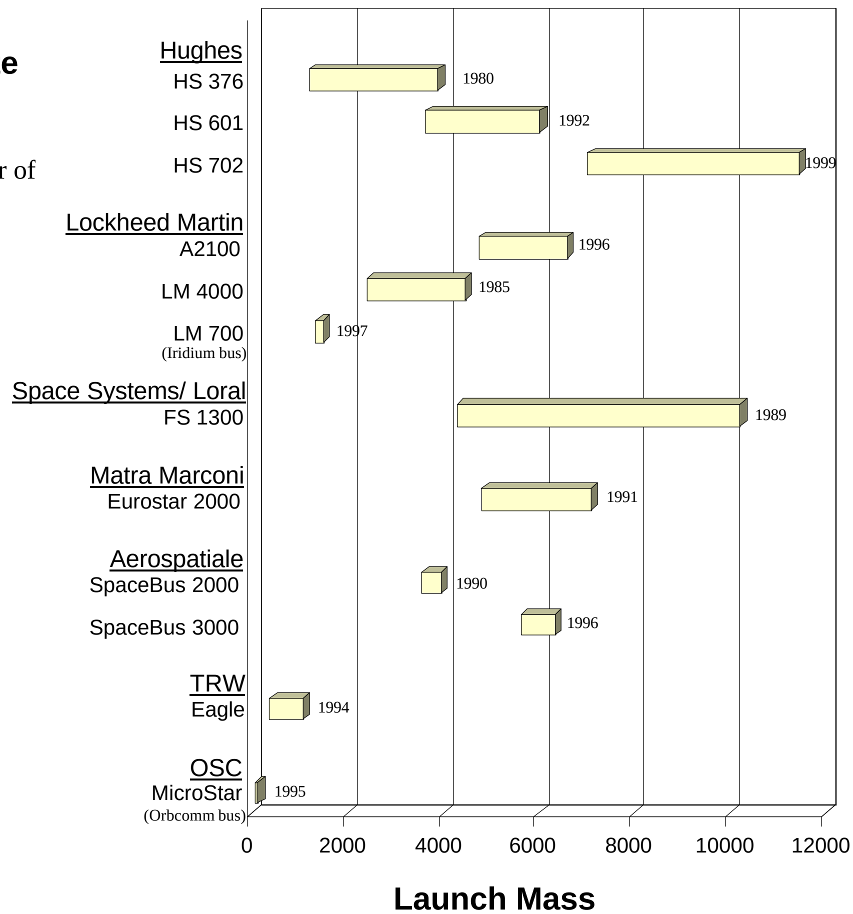
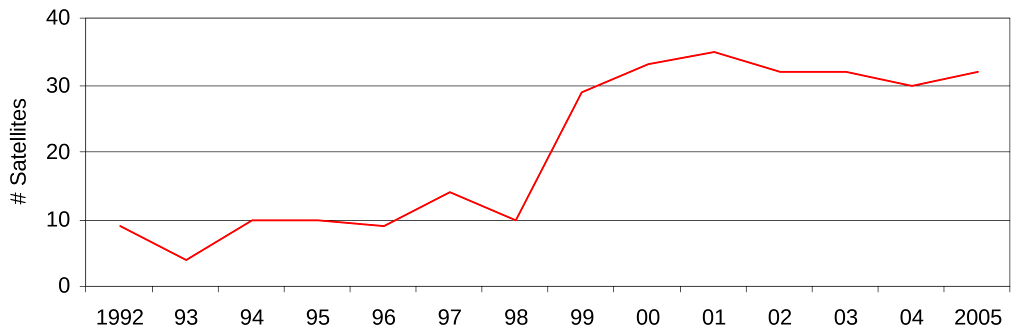


Figure 4: Commercial GEO Satellites Launched/Scheduled to be Launched Per Year (1992-2005)



Source: STAR Database, COMSTAC Report (May 1998)

include commercial variants with GTO capacities greater than 10,000 pounds. Ariane, Proton, and Sea Launch are also offering heavier lift capacities to GTO.

Table 2: Current and Future Commercial GEO Launch Vehicles

Vehicle	Capacity to GTO (lbs.)	Launch Provider	Introduction Year
Atlas 3A	8,940	Lockheed Martin	1999
Atlas (EELV)	11,600	Lockheed Martin	2003
Delta 3	8,360	Boeing	1998
Delta 4 (EELV)	9,100	Boeing	2002
Ariane 5	14,990	Arianespace	1998
Sea Launch	11,050	Boeing Sea Launch	1999
Proton	10,175	ILS, Krunichev	1996*
H-2A	8,800	RSC	2000

*Although the Proton has been in use since 1967, the first commercial launch did not occur until 1996.
SOURCE: STAR Database

The proliferation of launch service providers offering service to GTO is another result of the increased demand for GEO launches. With an increase in the number of payloads awaiting launch, the market could support additional launch providers. As a result, the Sea Launch consortium and International Launch Services have emerged to join Boeing, Lockheed Martin and Arianespace as GEO launch service providers. Additionally, the Proton and Delta 3 have arisen as additional entries to the launch market currently served largely by Atlas and Ariane.

PanAmSat's Galaxy XI satellite, a Hughes-built HS-702, demonstrates both the trend towards increasing mass and the need for larger launch vehicles. Weighing approximately 9,900 pounds at launch, Galaxy XI is the heaviest commercial communications satellite built to date.[12] Original plans called for the satellite to launch onboard the inaugural flight of Sea Launch, which is capable of carrying over 11,000 pounds to GTO.[13] After the loss of Galaxy X onboard the failed inaugural flight of the Delta 3, however, PanAmSat searched for an established vehicle. PanAmSat was faced with one hurdle: the launch mass of Galaxy XI comes close to

[12] *ISIR* 11/23/98, p. 27
[13] STAR Database.

the lift capacity of most vehicles in service – the Atlas 2AS, for instance, can carry only 8,196 pounds to GTO.[14] Currently, Galaxy XI is scheduled for a 1999 launch on board an Ariane 44L, which has a GTO capacity of 10,903 pounds.

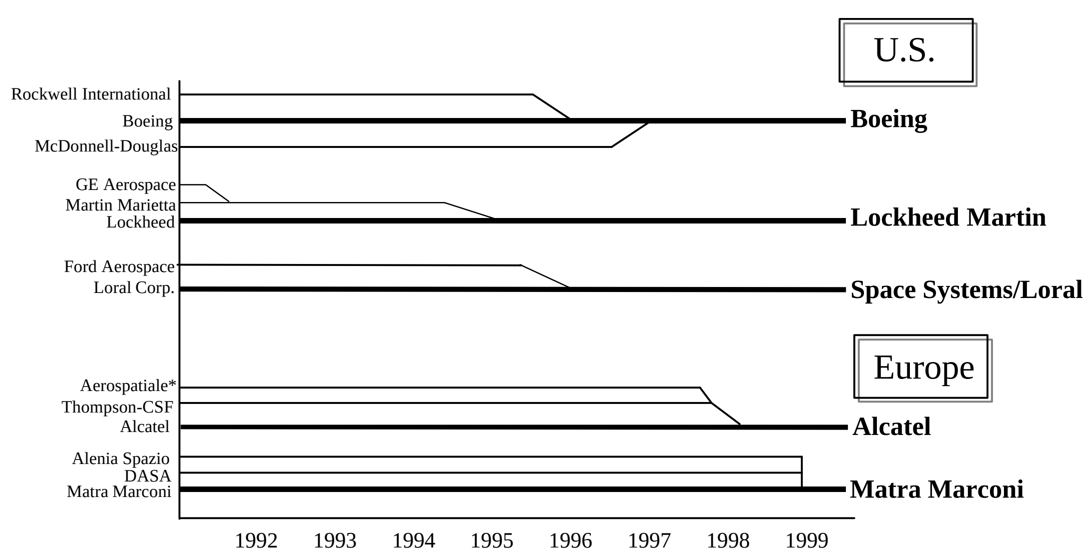
CHANGES IN MANUFACTURING FACILITIES

During the 1990's, the world's aerospace industries have undergone a major consolidation. In particular, economic forces following the end of the Cold War have caused the rearrangement and consolidation of the United States' aerospace industry, as various companies attempted to retain profitability in a period of reduced defense spending. As a result of the general reorganization of the aerospace industry, multiple corporate mergers led to a reorganization of the satellite manufacturing aspects of the aerospace industry in particular (Figure 5).

The increasing use of mass-production techniques in the satellite industry has made it desirable to consolidate not only production techniques, but production facilities as well. This trend has been reinforced by the desire to combine duplicative facilities inherited from previous owners. Three of the industry's largest manufacturers – Lockheed Martin, Hughes Space and Communications, and Space Systems/Loral – have all moved towards consolidation of facilities and practices within the last few years.

Lockheed Martin's satellite production plants provide one such example. Lockheed Martin inherited plants in East Windsor, NJ, and Valley Forge, PA, from General Electric via Martin Marietta. In October 1996, Lockheed Martin consolidated satellite production into the newly-built Astro Communications Production Facility at the Lockheed Martin Missiles and Space complex in Sunnyvale, CA, replacing the other factories.

Figure 5: Major Satellite Manufacturer Reorganization



*Satellite division only

[14] STAR Database.

The Astro Communications Production Facility is intended to triple Lockheed Martin's satellite production capacity while reducing manpower demands for an individual satellite by 35 to 40 percent. At times, Lockheed Martin's New Jersey plant experienced production bottlenecks that resulted in the shipment of satellites to Lockheed Martin's Pennsylvania plant. Many of these delays resulted from the uneven growth of the older production facility and will be solved by the design of the new Sunnyvale plant. Computer-aided designs used in the planning phase of the new facility are intended to facilitate work flow and avoid the sorts of blockages that affected the previous facilities. For example, the major test facilities have been built within the manufacturing clean room for easier access.

Hughes Space and Communication Co., the industry's largest manufacturer of commercial satellites, has also consolidated its production facilities. Its Integrated Satellite Factory (ISF) in El Segundo, CA, combines operations from ten different Hughes facilities. The ISF, which was originally purchased in 1955, underwent major modifications in 1992; an additional 41,000 square feet of testing facilities were added in 1998.[15] The ISF has reduced the number of buildings occupied by Hughes satellite manufacturing operations from 44 buildings in four California cities to 22 buildings all located in El Segundo, California. Hughes reports a ten-percent annual increase in production efficiency in the 1992 through 1996 period of operations, with production cycle times reduced by 30 percent. Average output is 14 commercial spacecraft a year, but the ISF is designed to produce up to 20 annually.[16]

Space Systems/Loral built its state-of-the-art Palo Alto satellite production facility in 1992. This facility was designed to help Space Systems/Loral expand into the commercial marketplace and did not replace a comparable facility, as did Lockheed Martin and Hughes. Nonetheless, this facility also demonstrates the current trend towards integrated, efficient, satellite manufacturing facilities. The Palo Alto plant uses a computer-based manufacturing system that would have allowed overflow production to be picked up by Space Systems/Loral's European partners (before Loral's buyout of these partners). The Palo Alto facility is capable of producing nine to twelve satellites per year.

CHANGES IN CONTRACTING

The effects of the growing use of off-the-shelf components by satellite manufacturers is evident in the organization of several recent satellite construction contracts. Contrary to previous practice, companies that are not constructing the bus can become the prime contractor for a satellite program. One such contract, between Iridium and Motorola, has already been mentioned – Motorola is the prime contractor, but Lockheed Martin is the bus manufacturer. This is also found in the contract for Australia's Optus C1 GEO communications satellite. Although Space Systems/Loral will provide the bus for this satellite, Japan's Mitsubishi will serve as "prime negotiator."

CHANGES DIVIDING COMMUNICATIONS FROM SCIENCE

As a result of the changes in manufacturing procedures and facilities, a two-tiered manufacturing industry has emerged. The first tier includes manufacturers rising to meet the market demand for LEO and GEO

[15] *AeroWorldNet* March 1998.
[16] *Industry Uplink* Spring 1995.

communications satellites. In order for the manufacturers to meet this demand, very large capital expenditures were required to build the "factories of the future" capable of producing higher numbers of satellites in a short period of time. Companies in this first tier include larger manufacturers, like Hughes, Lockheed Martin, and Space Systems/Loral, who have changed their practices in order to meet the market demand. The second tier involves small-satellite manufacturers meeting another market demand: the need for one-of-a-kind scientific, remote sensing, and interplanetary missions. Companies like AeroAstro, Spectrum Astro, Ball Aerospace, and Surrey Satellite Ltd., as well as microsatellite manufacturers, still maintain smaller, more customized procedures, and have not turned towards the assembly line process.[17]

IMPLICATIONS AND CONCLUSIONS

Just as satellite manufacturers have changed the way they do business in response to the needs of their customers, the launch providers are responding to the needs of the satellite manufacturers. The growing number of GEO satellites to be launched has attracted new entrants to the launch service market, including Proton, Delta 3, Long March, and Sea Launch, greatly expanding industry capacity. The growth in satellite size and mass has also driven the incorporation of increased lift capacities into the Ariane 5 and Atlas 3, as well as the Lockheed Martin and Boeing's EELVs. The arrival of commercial LEO constellations has stimulated demand for medium and intermediate vehicles for constellation deployment, and has inspired entrepreneurs to pursue RLV technology to meet the projected demand for LEO launches.

The launch services industry will face several challenges in the coming years: to accommodate a greater number of payloads, to accommodate heavier payloads, and to launch them within a shorter time period than in the past. As more service providers enter the marketplace, each will face vigorous competition to offer the best in terms of price, reliability, and availability.

[17] Interview with AeroAstro engineers, 12/18/98.