GEO Commercial Satellite Bus Operations: A Comparative Analysis

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1.0 Executive Summary

This report offers a form of "consumer report" evaluating the operations characteristics and preferences of operators for the 3-axis stabilized bus types currently being sold. Futron prepared this report by interviewing operators' satellite operations teams and manufacturers of operations sytems, along with some secondary research. While many of these results are necessarily qualitative, and often represent perceptions colored by some particularly good or bad experience an operator may have with a given spacecraft, we have nonetheless identified a number of patterns across multiple systems.

This study resulted in the following key findings:

- Operators increasingly face the challenge of operating more than one bus type - over 30% today's operators own more than one bus type

- Satellite operations is becoming more complex as satellites add capabilities, thus the cost of satellite operations becomes increasingly important to operators

- The size and cost of satellite operations is largely related to the size and complexity of the fleet being operated as well as management issues such as employment practices

- While operator error is a very small contributor to on-orbit satellite anomalies, managing the impact satellite anomalies consumes a considerable percentage of satellite operations' staff time

- The most overall favorable comments with regard to ease of operations and customer support were for the A2100.[1]

2.0 Background

Commercial satellite operators consider many factors when ordering a satellite: price, technical characteristics, reliablity, delivery schedule, reputation of manufacturer, previous experience with manufacturer, and ease of operations. Given the current environment in which operators are placing greater emphasis on constraining operating costs, the ease of operations, and potential related cost-savings, take on greater importance among those factors. Many operators involve satellite operations staff in the planning and procurement of new satellites to ensure this is considered. While many operators can make internal evaluations based on experience with operating multiple bus types, sometimes these are limited to multiple bus types from a single vendor, or to bus types that are hard to compare from an operations perspective (e.g., spinners and 3-axis stabilized).

This report starts with a brief review of the range of satellite bus types now in operation and those currently being marketed, before focusing on the 3-axis stabilized spacecraft of which there are a number of alternative designs, and which are the dominant bus types being sold today. The areas reviewed included evaluation of the key items impacting the size and scope of satellite operational infrastructure and staff and the customer support provided by satellite manufacturers.

[1] It should be noted that nearly all operators with long term experience consider the Hughes/BS 376 the easiest of all buses to operate. However it is an old 'spinner' design, fundamentally different from the modern 3-axis stablized buses of today, and thus was not included in our comparison.

3.0 Methodology

This study of the operations of currently-available 3-axis stabilized GEO commercial satellite bus types is based on data collected by Futron through telephone and email interviews with current and recent senior satellite operations staff in 8 major satellite operators in North America, Europe and Asia. While all of the companies interviewed operate multiple bus types, an effort was made to interview operators with differing experiences: some operating only or primarily one type of bus, some operating spacecraft from different manufacturers, some with a mix of US and European-built spacecraft. While many of the operators have BS376 spin-stabilized satellites in their current fleets, as well as older 3-axis stabilized satellites (e.g., LM heritage satellites of the 3000, 4000, 5000 and 7000 series), operators' experiences with satellite buses no longer commercially available was discussed only tangentially.

The issues covered in the interviews included:

- Key items impacting the size and scope of satellite operational infrastructure and staff
- Numbers and costs of people required to operate the different satellites
- Ease and costs of arranging follow-up/troubleshooting support from the satellite manufacturer
- Costs and ease of operating infrastructure, including manufacturer support

While interviews are necessarily subjective to some degree, Futron has extensive experience in the design and use of interview and survey tools that produce structured and quantifiable results. These interviews were supplemented by secondary research using Futron's proprietary satellite industry databases, as well as research on and interviews with the providers of satellite operations systems.

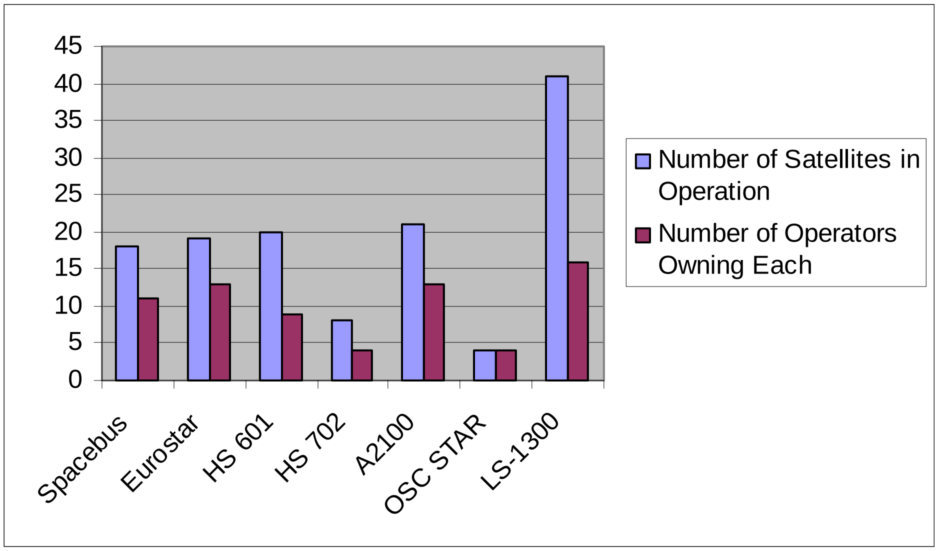
4.0 Background on satellites in operation

Operators today have a wide array of choices when procuring new spacecraft. As shown in the following Tables, there are currently 9 different major bus types in operation by commercial telecommunication satellite companies. The vast majority of these are 3-axis stabilized spacecraft, and of these 7 are currently marketed by 6 manufacturers.

Table 1: Major Commercial GEO Telecommunication Satellite Bus Types In Operation

Manufacturer	Spin Stabilized	3-Axis Stabilized
Alcatel		Spacebus
Astrium		Eurostar
Boeing	BS 376	
Boeing		BS 601
Boeing		BS 702
Lockheed Martin		LM Heritage
Lockheed Martin		A2100
Orbital Sciences		OSC STAR
SS/Loral		LS-1300

Table 2: Currently Available Major 3-Axis Stabilized Commercial GEO Telecommunication Satellites



Operators today face greater complexity in satellite operations

No matter which of the above-listed satellite bus types an operator procures, the major factors impacting the ease and cost of operating the satellites include: the number of telemetry points monitored, the frequency of station keeping maneuvers, the development of command sequences, and the operations systems.

As the capacity of all satellite buses has increased, so has the complexity of the satellite monitoring systems. The number of telemetry points that an operator needs to monitor has increased dramatically. This feature allows the operator to have more insight into every technical and operational parameter of the bus, but it adds an element of complexity to the system and requires satellite operators to develop a more in-depth and detailed understanding of these new satellite designs. The implications of this are found in the increased 'required knowledge-base' sought in contemporary satellite ground station engineers, which increases the costs of engineering staff.

Over time, enhanced satellite on-board computing capabilities have resulted in addition of software embedded to enable the day-to-day operations. Older satellite platforms used to have very little or no on-board software, most of the operations were mechanical. Now virtually all operations are software driven. Again, this facilitates the controllers' work, but it also increases the training and skill requirements and hence the costs of operations staff.

In addition, autonomous operations have been implemented in all platform types. Operators have very conflicted views of autonomous operations: they can help reduce costs of routine operations, but can substantially increase costs during contingencies or failures. While in the long term autonomous operation capability will likely reduce the absolute number of ground station engineers necessary for satellite control and maintenance, in the short term it adds complexity because engineers must manage large amounts of data and must execute a greater number of processes and carry out extended analysis when a problem does occur. In the words of one engineer interviewed, autonomous operations significantly "adds to the complexity of the fault tree, when the ground staff are attempting to diagnose exact causes of failures". Nevertheless, operators do recognize the long term benefits. One operator stated, "..although new bus models (have) become more complex, autonomous operations is a significant offset: the requirements to operating staff would have been be much higher without them." Others opined that manufacturers would be better off embedding complexity in the ground segment, not in the space segment, thus making problem-solving easier on the ground.

Since the cost increases caused by managing autonomous operations are found in dealing with anomalous situations, it is useful to note that on-orbit TT&C-related satellite anomalies are caused both by hardware malfunctions and operator error, with the latter potentially attributable to the complexity of operating a given spacecraft. Based on the Airclaims SpaceTrak database there were 10 TT&C anomaly occurrences for the 3-axis stabilized satellite buses currently marketed. This represents a very small percentage of total anomalies reported for the subject bus types. Of the 10 anomalies 5 could be attributed to "hardware malfunction", and the remaining 5 could be attributed to "operator error". The finding by bus type are outlined below:

Alcatel (Spacebus):
- Spacebus 3000: 2 operator error, 1 hardware malfunction

Astrium (Eurostar):
No TT&C anomalies on Eurostar busses under consideration

Boeing (BS 601 and 702):
- BS 601: 1 hardware malfunction, 1 operator error
- BS 702: 2 operator error

Lockheed Martin (A2100):
- No TT&C anomalies

Orbital:
- No TT&C anomalies

SS/Loral (LS1300):
- 3 hardware malfunctions

Operators also face the challenge of operating multiple bus types: over 30% of today's operators "fly" more than one bus type

Nineteen commercial satellite operators have more than one of the currently-available satellite bus types in operation, as shown in Table 3. Of these, thirteen operate more than one of the currently-available 3-axis stabilized satellites (all those listed below except for the BS376), and a quarter of them operate 3-4 types.

The implications of these multi-bus operations on cost is significant, as there is a need for controllers and other satellite operations staff to be trained on the operational requirements of each bus type. There are companies such as Integral Systems, Inc. who have developed ground control systems to facilitate multi-bus

Table 3: Satellite operators with more than one currently-available bus type

Operator	HS 376	HS 601	HS 702	LS 1300	OSC Star	A2100	Spacebus	Eurostar	Current Bus Models in Operation	Current 3-Axis Bus Models in Operation
PanAmSat	X	X	X	X	X				5	4
JSAT	X	X		X		X			4	3
SCC		X		X		X			3	3
SES Astra	X	X						X	3	2
Telesat Canada	X		X			X			3	2
Optus/SingTel	X	X						X	3	2
SES Americom						X	X		2	2
New Skies				X		X			2	2
Loral Skynet				X				X	2	2
Hispasat							X	X	2	2
Eutelsat							X	X	2	2
Echostar				X		X			2	2
DirecTV		X		X					2	2
Shin	X						X		2	1
PT Telkom	X					X			2	1
NSAB	X						X		2	1
Intelsat	X			X					2	1
BSAT	X				X				2	1
AsiaSat	X	X							2	1

NOTE: JSAT and SCC share one A2100 satellite

operation by providing software tools that offer a unified look and feel to operations of multiple satellite types. In addition, there are ESA-developed standards and protocols followed by Alcatel and Astrium. Despite the use of such systems, a number of operators commented that their own analysts and engineers must still develop maneuver plans and procedures that are affected by the different qualities of each bus type, as discussed in more detail in the following section.

5.0 Review of costs of satellite operations

The major components of satellite operations costs are those for staff and the infrastructure (hardware and software) for spacecraft monitoring and maneuvering. The staff costs can be divided into:

- ongoing spacecraft control – largely by lower-cost controllers
- planning routine maneuvers – largely by higher-cost orbital analysts and engineers
- planning and execution of anomaly-related maneuvers, again using higher-cost staff; and
- training of engineers, analysts and controllers when a new generation of satellites is launched, or when new operating hardware/software is installed.

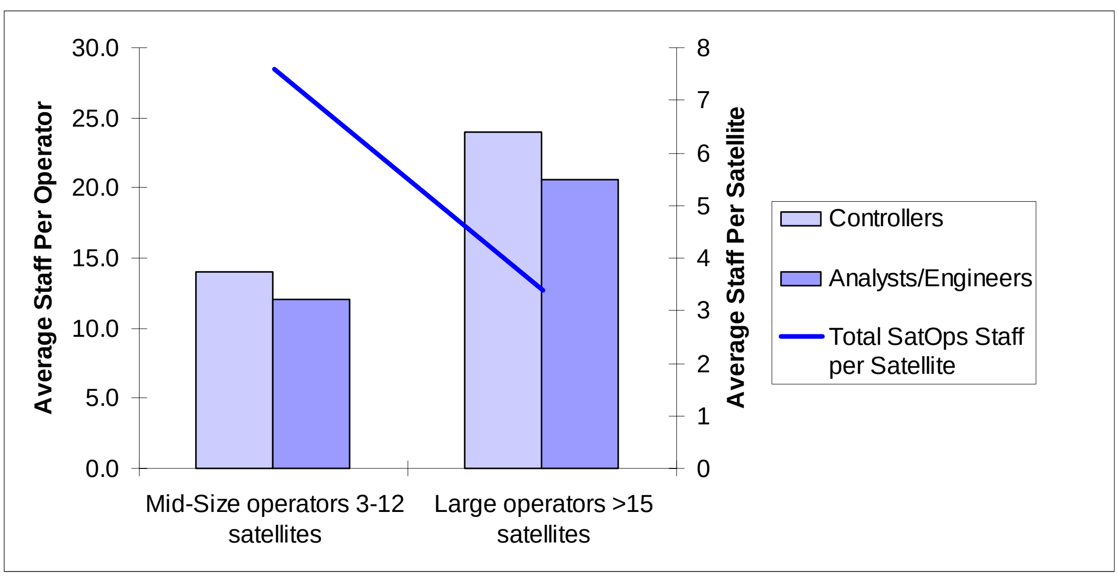
Overall staff costs vary by fleet type and management approach

The numbers and levels of staff assigned to each of these activities varies by operator, depending on the numbers and types of different satellite bus types being flown by the operator. Overall operators report that satellite operations staff spend 20-40% of their time on anomaly-related activities, with the rest on routine maneuver planning, development of new procedures, preparations for new satellites, etc.. At the lower end of anomaly-support time was an operator who, while experiencing some significant anomalies, chose to have one manager do virtually all of the interfacing with the manufacturer, and plan as well as direct the compensating maneuver activities. This is obviously not an inexpensive choice, but it did eliminate the need to expand shift operations, albeit at the cost of more strategic business planning activities. Another operator with anomaly activity at the high end of the range noted above specifically involves as many staff as possible in anomaly investigation and resolution work as a learning activity. While both situations involved difficulties with LS1300 spacecraft, the cost impact will be quite different in each case.

This related to a key finding in our research, which is that perhaps the most important determinants of staff levels are management policies on the numbers of control facilities and the numbers of control staff shifts. The former is a corporate risk decision (including the anomaly-related assignments noted above) while the latter is usually driven by outside employment directives involving labor unions and government labor regulations. Even within the shift operations, some operators expressed strong views on the numbers of satellites assigned per controller or analyst/engineer per shift. Some use the bus type as a determinant, with one stating he specifically assigns a mix of satellite types to each controller to vary their workload. Another, smaller, operator assigns engineering staff to monitoring and management of functions – ADCS/TT&C vs payload, power and thermal – rather than to specific satellites.

Next most important is the size of the fleet being managed. As shown in Table 4, the relative proportion of controllers to analysts/engineers is fairly constant regardless of the fleet size, with larger fleet operators having a slightly higher proportion of analysts and engineers. What does change dramatically is the number of total satellite operations staff (including management and other functions) per satellite, which declines dramatically as fleet size increases. While the figures in the Table are averages of the companies studied, the relationships hold true for operators of all satellite bus types interviewed, in part because so many operators have such mixed fleets.

Table 4: Average satellite operations staffing levels



As Table 4 shows, controllers represent about half of the satellite operations staff in any size organization, and have a typical fully-loaded annual cost of some $60-100K per person, depending on experience and seniority. Analysts and engineers represent a slightly lower percentage, but generally have higher costs, in the range of $100-130K per annum fully loaded. While the numbers of staff may be most strongly influenced by exogenous factors, it is clearly desirable from a staffing perspective to have a satellite bus design that facilitates operations by controllers, with reduced effort on the part of higher-cost analysts and engineers.

The infrastructure costs for satellite operations– hardware and software – also vary by the size of the fleet being operated, driven by the fact that basic costs must be incurred for even the smallest fleet. For this reason many small operators – those with one or two satellites – outsource their satellite operations to a larger operator. As shown in Table 5, however, this does produce significantly higher costs per satellite on both an annualized and total life basis. The cost ranges in Table 5, drawn from Futron's interviews and secondary research, assume a standardized 15-year satellite life, and indicate that the costs of operations can be a significant percentage of the total system costs, particularly for those operating small and mid-sized fleets.

Table 5: Typical costs of satellite operations by size of fleet operated

	Annual Staff Costs per Satellite	15-Year Staff Costs per Satellite	Infrastructure Costs per Satellite	Total Operating Costs per Satellite
Small Operators (1-2 satellites)	\$1.25M - 1.5M (outsourced)	\$18.75M - \$22M (outsourced)	(outsourced)	\$18.75M - \$22M (outsourced)
Mid-Sized Operators (3-12 satellites)	\$0.4 - \$0.75M	\$6M - \$10M	\$3M - \$6M	\$9M - \$16M
Large Operators (>15 satellites)	\$0.25M - \$0.5M	\$3.75M - \$7.5M	\$2M - \$4M	\$5.75M - \$11.5M

In further explanation of the variations among operators, several interviewees noted that it is the number of bus types being flown, rather than the number of satellites, that is the most relevant to the number of engineers as a driver of costs, despite the fact that most operators now have integrated software packages that can be used in operating a multi-bus fleet. It is in this area that some of the strongest and most detailed insights have been provided by operators regarding different bus types.

A few key technical issues have the greatest impact on operational costs and ease of operations

As noted above, the primary technical issues impacting the ease or complexity of operating one satellite bus versus another can be tied in one way or another to the number of telemetry points monitored, the frequency of station keeping maneuvers, and the development of command sequences. These impact all aspects of satellite operations, from the spacecraft operation, TTC&M, and related ground network system operation. While each operator manages these factors differently (and there is wide variation in the approaches to operations management) and while this is further complicated when multiple bus types are being operated simultaneously, Futron has identified a number of patterns connected with individual bus types. In interviewing operators the following areas were identified as most seriously impacting operations staff resources:

- Attitude control
  - The constant maneuvers required for attitude control were consistently identified as requiring the most time and attention from both the controllers and higher paid analysts and engineers who must develop the maneuver procedures.
  - One operator singled out the A2100 as “the nicest bus to fly, in particular from the ACDS perspective. It has lots of automation on board and is easy to understand.” This operator specifically praised the A2100’s automated management of sun or “second source” interference. He went on to note further on the A2100: “the on-board fault protection logic is very good – it catches rate errors, etc. And the TWTA automatic restart mechanisms are good. The A2100 has lots of telemetry data – such as the auxiliary telemetry stream that makes it easy to configure telemetry data by looking at different parameters.”
  - Other interviewees complained about excessive telemetry data, commenting on the OSC Starbus: “7,000 telemetry points is overkill and adds complexity”, a situation exacerbated on the BS702 which has 13,000 telemetry points.
  - Another operator expressed concern with the complexity of the “active” 3-axis control on the Eurostar 3000 series.

- Propulsion and Power
  - The propulsion systems used to conduct the attitude control maneuvers vary by bus type, and clearly affect the complexity and cost of spacecraft operations. Specifically, the Xenon Ion Propulsion Systems (XIPS) used by Boeing was identified as requiring additional time to develop plans and programming to accommodate a larger number of maneuvers that the XIPS uses to maintain the satellite’s station-keeping position. Some operators found this overly time-consuming, especially in relation to systems on the A2100 and Eurostar. Others were more sanguine about the XIPS, noting that “when they work as designed, from the planning side they’re more complex & difficult, but from the ops execution side – the controllers on the floor – it’s easier because you can plan 2 week execution cycles.”

- Commanding
  - Effective use of power and propulsion, and conduct of attitude control maneuvers are dependent on the commands sent to the satellite. Operators expressed concern with the need to avoid incorrect commands, often a result of complex operating systems. While each bus type and generation of spacecraft has its own command structure, with the trend towards use of multiple bus types, many operators have moved to implement a standardized set of operations systems to make it easier for controllers to “fly” any and every satellite in a given fleet. The complex and cost-intensive actions here are in the development of command programs. It is for this reason that one operator, in discussing his management of satellite operations for four different bus types, described the impact of this as being only moderate from the point of view of the satellite controllers and spacecraft engineers, but significant from the perspective of the orbital analysts and the software/data maintenance.
  - In this connection one operator stated that: “The A2100 is good because it’s simple to operate, does what it needs to do and doesn’t force your hand to send commands at specific times. The A2100

provides capability for an operator to create simple build-ons to the on-board safety protection logic, for example."
    - This same operator continued: "At the same time the LS1300 has ability to plan a whole year at a time of time tag cues which reduces analysts and controller efforts – or at least drops the work from commanding to monitoring."[2] The LS1300's simple command structure and easy to review database of commands was also noted.
    - Another interviewee complained about both the Eurostar and Spacebus, noting that they work in CCSDS: "which makes no sense for GEO, works for LEO but adds unnecessary characters to command and telemetry strings".

- Infrastructure for spacecraft monitoring and control
    - For those operators operating multiple bus types using multiple ground control systems, adding a new bus type is particularly costly in terms of equipment costs as well as staff time for training.
    - For this reason most operators are now moving to integrated systems, which provide a consistent screen "look and feel" for the controllers regardless of the number of bus types being flown. The costs for these systems are basically similar, as one operator noted, it's the same hardware, regardless of bus type, so "it's the same price overall, a couple of million dollars." The biggest variables are the number of control facilities, and the potential costs of connecting multiple sites.
    - But there are significant differences reported in the ongoing software development required for each bus type. Specifically, a number of operators reported that screen layout development layout is easier for the A2100 than for the FS-1300 in terms of the mnemonics used by Lockheed Martin, and because "A2100 block diagrams are very straightforward and easy for controllers to duplicate on the screen." One commented that the Eurostar screen layout is also difficult.
    - One operator termed the BS702 "not user-friendly for the ground system", and another commented that the BS601 and BS702 "have lots of memory management needs…and need a bigger processing platform."

- Training
    - As noted above, most operators already have or will soon deploy integrated operations systems, which does simplify training somewhat. Nevertheless, there are still significant differences experienced in learning to operate the different bus types. Training on a new bus type typically involves 1-2 months of training for the full satellite ground operations staff, with more for engineers who will be doing ongoing plan development. The extent of the training, and any associated costs, are usually negotiated as part of the satellite procurement package, and the costs (other than staff time) are thus not transparent.
    - Comments we received on training include:
        - "It's a lot easier to take over flying an A2100 than an LS1300" as a result of the cumulative effect of items related to getting staff to understand how to fly the satellite, specifically "easier telemetry layout, easier maneuver procedures, and easier to use ops manuals."
        - "The Eurostar was the most difficult to add – took 3 months of hard training."

[2] While this was the only specific mention of time-tagging capabilities in an interview, other bus types, such as the A2100 also have this capability.

        - "Boeing training is pretty good, but their operation procedures are not good and not well presented."

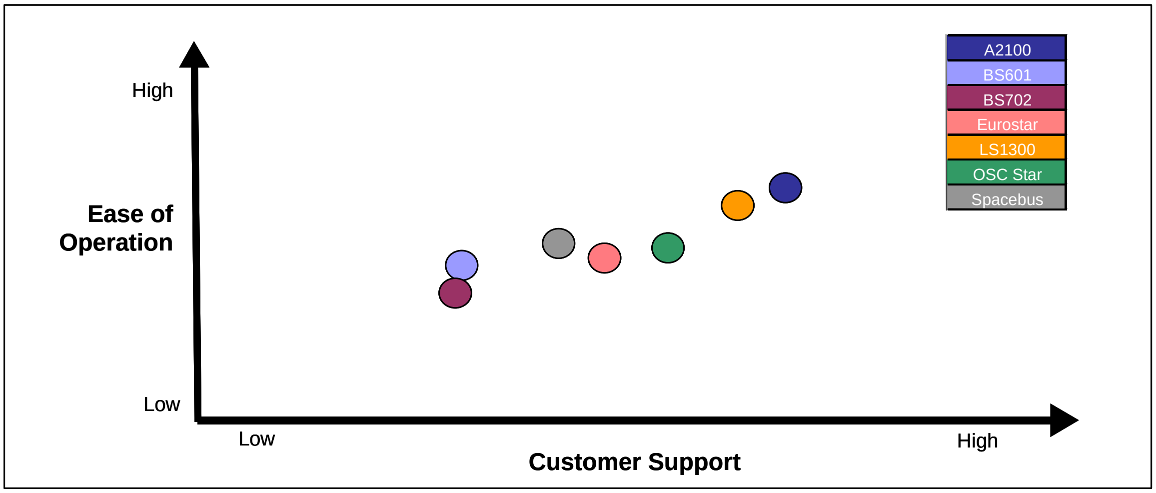
- Anomaly support and reconfiguration management
    - One unsurprising set of comments here came from multiple operators who have had joint-ownership with manufacturers, and who reported easier relationships with those manufacturers, including greater attention and more manufacturer-provided engineering support.
    - On the other hand one operator with no such ties reported widely varying experiences with different bus types, largely related to the satellite characteristics, but enhanced/exacerbated by the manufacturer: "For a major payload reconfiguration it takes 2-3 hours for the A2100 and 2 days for the FS 1300."
    - Another interviewee noted that the BS 702 is: "OK as long as nothing goes wrong", but it has very complex fault tree diagrams that are difficult for engineers and operators to figure out, "if a problem occurs and recovery is triggered, it is difficult to determine correct path for future ongoing operations".
    - The primary concerns with Eurostar and Spacebus customer service were that, unlike the American vendors, both Alcatel and Astrium have explicit charges for technical support, even in the case of satellite anomalies. While the U.S. manufacturers undoubtedly include such costs in their contracts, it is not visible to the satellite operations staff, and is thus not a concern to them when they need assistance. What does trouble them is the more recent complications with Boeing and, to a lesser extent SS/L, in the form of additional legal review bottlenecks that have delayed responses and support for problem resolution. On the other hand European and Asian operators have begun to find ITAR restrictions making it more difficult for them to get quick responses in resolving problems on U.S. manufactured satellites. They have developed work-arounds, but these add cost and time.

6.0 Overall, the A2100 received the most favorable comments with regard to ease of operations and customer support

Some interviewees plainly stated they do not have a preference to work with particular satellite buses over others. From their point of view, the past experience in operating a specific bus is the primary advantage, coupled with the known relationship with the manufacturer.

When asked to compare the currently available buses regarding ease of operations and customer support, LMCSS and the A2100 in particular received the highest ratings. The LS1300 was a close second, with Boeing's BS601 and BS702 performance complexity and problems along with declining levels of customer support sited consistently as causing their low ratings. The OSC Star is a new entrant, and while the limited experience is not bad, it was cited as merely average.

Chart: Operator Evaluation of Ease of Use and Customer Service of Currently Available 3-Axis Stabilized Satellite Bus Types



7.0 Conclusions

Industry sentiment does favor some bus types over others when it comes to operational features. The specific reasons vary from technical characteristics to customer support.

Unfortunately, although on-orbit operations of a satellite will span 15 years or more, too many operators place their procurement emphasis on other aspects of the satellite design such as capacity, power, mass, etc. The costs of satellite operations are often overlooked in the planning for new satellite procurements, partly because ground operations divisions are not profit-centers for most operators (the exceptions being those who provide this service on a contract basis to others). In addition, items such as operations software and training are often incorporated into the manufacturing contract as part of the deal, and are thus not readily identified and understood as ongoing expenses. This has led to many manufacturers and operators leaving these divisions and the procurement of operational support hardware, software and staff to almost an after-thought.

With the move to more diverse fleets, and complex operations, it appears that, in the first stages, the greatest efforts have been made by the companies developing integrated operations systems to take the lead in resolving the cost impact of the need to operate more complex bus types, and a greater variety of them. Ultimately, however, operators will have to take responsibility for improving their own efficiency in satellite operations. As a first step it is clear that the satellite operations staff should be involved in discussions and consideration of new procurements from the beginning of the process, to ensure that the long-term implications of choosing one bus type over another are fully understood. The long-term costs of having a satellite that is difficult to operate, or for which it is difficult or costly to obtain manufacturer support, needs to be reflected in any satellite procurement decision.

Futron Overview

Futron Corporation is a technology management consulting firm. Futron applies analytically rigorous decision-support methods to transform data into information. We collaborate closely with clients to relate decisions to future outcomes and measures of value. Our aerospace consulting services include market and industry analyses, safety and risk management, remote sensing, and communications and information management. Futron was founded in 1986 and is headquartered in Bethesda, Maryland with a branch office in Houston, Texas. Futron employs approximately 100 professionals and has annual revenues of over $10M.

Futron's headquarters in Bethesda, Maryland

Summary of Capabilities

Futron's Space and Telecommunications Division is the industry leader in researching, analyzing, and forecasting space and telecommunications markets and programs. Futron offers our commercial and government clients a suite of proprietary, leading-edge analytic methodologies. Our world-class team of market and policy analysts, economists, and engineers bring unparalleled skills and expertise to each account.

- We have surveyed hundreds of aerospace firms to develop a unique revenue, employment, and productivity profile of the industry.

- We have developed country-by-country models of demand for telecommunication services that aggregate a global forecast up from the individual household PC or business network; these models have accurately predicted future launch levels and business changes in the satellite industry.

- Futron helps clients win competitions, analyze competitors, estimate costs and prices, and track opportunities.

- Futron also performs cost estimates and economic analyses. Futron generates bottoms up, parametric, and analogous cost estimates for commercial satellite and launch vehicle programs.

- Futron provides a subscription-based service providing information on every FCC satellite application filed since 1990. Futron's FCCFilings.com is the only source for competitive intelligence and business data contained in FCC satellite licensing documents.