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ACCIDENTS OF SPACE ACTIVITIES AND INSURANCE

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Abstract

Space insurance is a highly complex subject. Since 1965, satellite insurance has become one of the principal means for owners and operators to manage their risk exposure. The satellite insurance market has recovered from major losses since 1987. However, there is no consensus in the satellite community on where the insurance market is going. Thus, satellite operators are pursuing a number of means to reduce risks. As new types of current space activities are emerging toward 2000 and beyond, there will be substantial needs for new types of insurance. In these circumstances, satellite operators should devise thoroughgoing measures to ensure against the successful satellite launch and operation. In this paper, the nature and causes of on-orbit failures are focused. The number of catastrophic on-orbit failures should decline, while new procedures in manufacturing, quality control and satellite operations may be expected to mitigate the severity of many partial failures. Ultimate causes of failures still remain difficult to ascertain. Consequently the space insurance market requires a great deal of technical data so that insurers could determine more accurately reliability of space systems.

1. The first space insurance policy

Insurance is one element of risk transfer which in turn is a component of the much wider activity of risk management. Over the past more than twenty years, the number of satellite operators has grown substantially, and satellite insurance has become one of the principal means for owners and operators to manage their risk exposure.

The first insturance policy for satellite was written in 1965 to provide prelaunch coverage for Intelsat's "Early bird' satellite. Insurers were concerned with coverage of the risks associated with satellites during the launch and on-orbit phases of a mission since insufficient data were available from prior experiences to properly assess the risks. However, after the loss of a satellite in 1968, Comsat approached aviation underwriters in an attempt to obtain a launch insurance policy covering the failure of its satellites to achieve proper orbit. The policy insured Comsat against the loss of one satellite in a five-launch series, allowing for one launch failure as a deductible.

In the 1970s, privately owned satellites were launched with increasing frequency, and insurers agreed to provide coverage as sufficient data on satellite reliability were amassed, enabling the accompanying risk calculations. In 1980, Corroon & Black Inspace was formed as the first company dedicated exclusively to the provision of space project insurance. Since then, a variety of other companies have entered the field, offering insurance to private and public clients owning or operating communications satellites[1].

2. The space insurance market

The satellite insurance market has recovered from a series of major losses over the past six years (See Figure 1). Cumulative losses through 1987 exceeded premia by approximately $300 million. The fundamental reason for this situation was underrating of launch insurance policies through 1984: premia were running at between

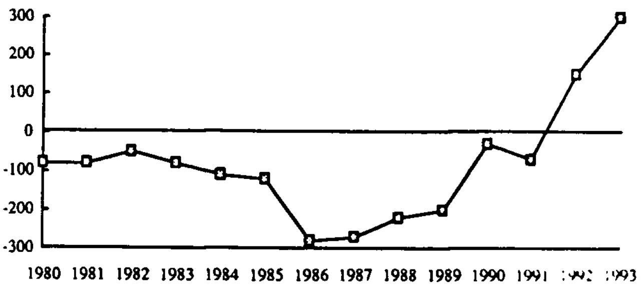

Figure 1 Space Insurance Market Capacity (Unit:$ Million)
Source: Society of Law and Policy on Space Utilization in Japan
by courtesy of the TOKIO Marine and Fire Insurance

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five and seven percent of insured value, while the historical failure rate was approximately fifteen percent. A series of major claims in 1984, 1985 and 1986 caused a major reduction in capacity. As well, rates surged far beyond the historical average, as underwriters attempted to recoup past losses through extreme rate increases for all types of space insurance[2)].

It is quite reasonable that a insurance broker projected that the space insurance market by 1995 could offer up to $350 million insurance to cover the value of a launch vehicle and its payload[3)]. Insurance capacity will provide enough coverage to insure the value of most launches through the mid-1990s. However, insurance providers remain wary of the high risks involved in rocket launches and satellite operations in space.

There is no consensus in the satellite community on where the insurance market is going. Thus, spacecraft operators are pursuing a number of means to reduce risks (See 5.1), although the actual mechanisms pursued by each company vary with financial health, present on-orbit capacity and future launch plans.

3. Background: prospects of world space industry

3.1 Civil space expenditures

Considering the actual prevailing world situation in the next century, space activities will take following directions;

(1) Large cooperative programs of global changes and security monitoring post cold war era
(2) Operational phase of International Space Station Freedom
(3) Development/operation of a new space transportation system of Earth to LEO and beyond, including Orbital Transfer Vehicle
(4) Development of manned space activity
(5) Development of advanced application satellites related to communications, remote sensing, material processing and space science

Given those assumptions, it is projected that world civil budget in NASA, ESA and NASDA will be expected to achieve growth rate of 7%, 2% and 7.5% respectively (See Figure 2). The different scenarios also give us the sight of promising space activities (See Figure 3). This figure shows that financial order of world civil space expenditures in scenario A (most optimistic) has been estimated $ 210 Billion by the year 2016[4)].

3.2 Evolution of the communications satellite market

Communications by satellite is the first and most attractive practical application of space technology. The communications satellite industry has during the last decade achieved its maturity and accounts for 70% of the total world civil space activities[5)]. The future demand for launch services will be determined by the number of communications satellites that are required to meet various communication needs of the countries. The requirement for all means of communication will keep increasing and satellites will have an important and significant role in such needs: hence the demand for more launch services.

Thus, for the forseeable future, the capital costs of satellite communications systems (including the spacecraft, launch services, ground control systems, and user terminals) will remain large in absolute terms.

At the current time, there are four major and interrelated trends affecting the demand for commercial communications satellites, and by derivation, the demand for commercial launch services[6)]. These are: (1) geographic proliferation of domestic and regional satellite communications system, especially in Asia (2) service proliferation (3) digitalization and compression of communications, and (4) liberalization of domestic regulatory conditions.

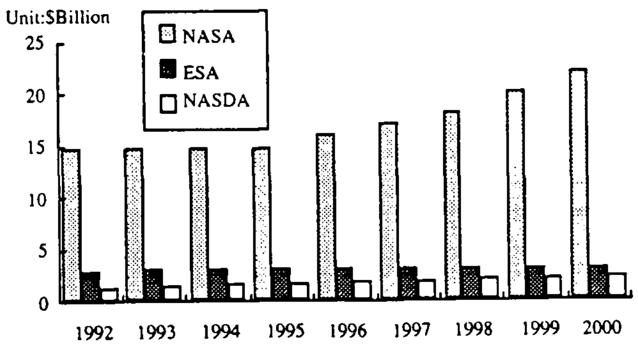

Figure 2 Space Budget in NASA, ESA, NASDA

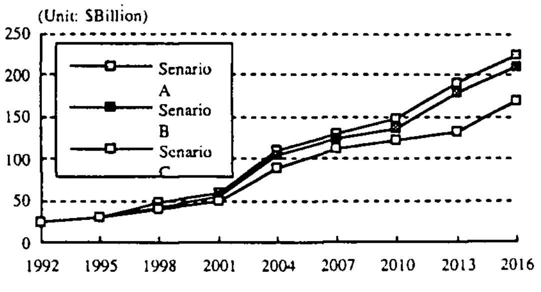

Figure 3 Forecast of World Annual Civil Expenditures
Source: Consultant Northam

4. Analysis of launch-related and on-orbit satellite anomalies on the public record

4.1 The nature of launch-related satellite losses

Table 1 indicates comparative characteristics of space systems in the number of parts items and price per ton which is obvious causing and resulting in serious damage when it suffers from failures: failures have also become more costly.

Table 1 Comparative Characteristics of Space System

<Number of Parts Items>		<Price per Ton>	
Sewing Machine	10^2	Building	$0.9k/ton
TV	10^3	Car	$8.2k/ton
Machine Tool	10^3	TV	$45k/ton
Automobil	10^4	Camera	$450k/ton
Jet Airplane	10^5	Jetliner Engine	$1300k/ton
Satellite Launch Vehicle	10^5 10^6	Gold Satellite	$27,000k/ton $270,000k/ton

From January 1963, beginning of the commercial communications satellite era through the end of 1990, there had been 205 launch attempts involving 239 satellites7). During these 205 attempts, 40 failures occurred causing 43 satellites to be either lost, injected into significantly incorrect orbit, or to suffer a loss of operational life capability. This launch failure rate represented over 19% of all launch attempts, which the satellite failure rate was 18%.

Table 2 also indicates satellite anomalies record that launch related failures consisted of almost 60% of all causes of failures from 1977 through 1992.

Most losses of communications satellites occur during the four distinct launch phases;

(1) From the launch pad to LEO, or its equivalent in the case of expendable launch vehicles
(2) From LEO to GTO
(3) From GTO to geostationary orbit, usually achieved by firing an Apogee Kick Motor (AKM); or
(4) During the commissioning phase in which the satellite is drifted to its allocated station, checked out, and brought to operational condition

Historically, the highest incidence of failure has occurred as a result of an upper stage anomaly during the transfer phase from LEO to GEO.

Table 2 Satellite Anomalies Records

Date of failure	Satellite	Failure phase	Launcher	Cause of failure	Total loss(T)/Partial loss(P)
1977. 9.13	OTS 1	(launch)	DELATA	Failure of first stage	T
1979. 2. 6	ECS 1	(launch)	N-1	Third stage/Satellite	T
12. 7	SATCOM 3	(launch)	DELTA	Failure of AKM	T
1982. 4.10	INSAT 1A	(early orbit)	DELTA	Anomaly of ACS	T
9.10	MERCS B2	(launch)	ARIANE	Failure of third stage	T
1983. 5. 1	SATCOM 2	(in orbit)	IN ORBIT	Failure of transponder	P
6.16	OSCAR 10	(launch)	ARIANE	Third stage/Satellite	T
1984. 2. 3	WESTAR 6	(launch)	STS	Failure of PAM	T
2. 3	PALAPA B2	(launch)	STS	Failure of PAM	T
6. 9	INTELSAT 5 F9	(launch)	ATLAS/CENTAUR	Failure of second stage	T
1985. 3. 8	ANIK D2	(early orbit)	STS	Anomaly of ACS	P
4. 12	LEASAT 3	(launch)	STS	Failure of PAM	T
5. 17	ARABSAT 1A	(early orbit)	ARIANE	Anomaly of ACS	P
6. 19	ARABSAT 1B	(early orbit)	STS	Shortage of fuel	P
8. 27	LEASAT 4	(launch)	STS	Open circuit RF feed to antenna	T
9. 12	SPACENET 3	(launch)	ARIANE	Failure of ignition (third stage)	T
9. 12	ECS 3	(launch)	ARIANE	Failure of ignition (third stage)	T
1986. 5. 31	INTELSAT 5 F14	(launch)	ARIANE	Failure of ignition (third stage)	T
1987. 11.17	TVSAT 1	(early orbit)	ARIANE	Failure of ignition (third stage)	T
1988. 7.21	INSAT 1C	(early orbit)	ARIANE	Solar array failed to deploy	T
9. 8	G SATR 3	(early orbit)	ARIANE	Failure of power supply	T
1990. 2. 23	SUPERBIRD-B	(launch)	ARIANE	Failure of AKM	T
2. 23	BS-2X	(launch)	ARIANE	Failure of first stage	T
8.	TDF 1	(in orbit)	IN-ORBIT	Failure of first stage	P
8. 31	BS-3A	(early orbit)	H-I	Failure of transponder	P
12.20	SUPERBIRD-A	(in orbit)	IN-ORBIT	Failure of power supply	T
1991. 4.19	BS-3H	(launch)	ATLAS/CENTAUR	Failure of ACS thruster	T
4.	ASC 2	(early orbit)	DELTA	Failure of second stage	P
6.11	AURORA 2	(early orbit)	DELTA	Failure of 3 transponder	P
1992. 8.22	GALAXY 1R	(launch)	ATLAS/CENTAUR	Reduced life-time by irregular thruster	T
12.21	OPTUS B2	(launch)	LONG MARCH	Failure of second stage	

Source: Space Debris Study Group Report by courtesy of the TOKIO Marine and Fire Insurance

4.2 The nature of satellite failures

Generically, the cause of spacecraft failures is likely to be either a faulty design, or the failure to manufacture an item to specified design standards. The former is broadly defined to include manufacturing and test procedures, and the latter is representative of quality control.

Failures of design are likely to occur more frequently in the early units of a spacecraft or launcher series, and totally prevented if the design achieves maturity. Ray Sperber of Luxembourg's SES issued a database of known spacecraft failures, in which nearly 34% of all known failures had occurred on the first satellite of a series, which appears to have twice the likelihood of failing as the second unit.

On the other hand, failures of quality control occur more randomly by a variety of causes, and can never be completely eliminated. Informed observers point that failures of quality control are attributive to the danger of quick, unplanned design changes, accelerated test and integration schedules, inadequately qualified manpower among some manufacturers, and pressures to keep costs in check, as contributing to "quality control" faults.

4.2.1 The main cause of failures

Design of most spacecraft is integrated with various redundant components to ensure against the random loss of capability. However, there are some items, such as fuel and power supply, which cannot be made redundant, which decrease with time and eventually result in the "death" of the satellite. The most critical component and subsystems which cannot be fully duplicated are the spacecraft power system, attitude control system and reaction control system. Loss of communications capacity may result from the failure of one of these subsystems, or through attrition of the communications package itself.

Serious anomalies caused by these of other factors generally produce one of the following results:

(1) Failure of transponders of other parts of the communications payload on the satellite
(2) Loss of control of the satellite caused by fuel exhaustion
(3) Loss of spacecraft power caused by deterioration of the solar array or power conditioning subsystem and
(4) Failure of the antenna or attitude control system

The effect of any failures will vary depending on such factors as the number of redundant transponders, the power margin at the beginning of satellite life, the fuel margin remaining once satellite operations begin, etc. Each of these characteristics and many others will be key to the severity of the anomaly in terms of its influence on satellite communications capacity. Any of these failure events can occur during the commissioning/checkout phase of the spacecraft or after it enters its useful life, catastrophic failures occur predominantly during checkout.

4.2.2 Anomaly classifications

The Sperber/SES database classifies some 355 spacecraft anomalies in accordance with type and severity. That data, combined with additional primary research, has been compiled by a result of the observations and conclusions as follows.

It is estimated that no more than 20% of all moderate anomalies are ever reported, meaning that those anomalies require moving to a redundant subsystem, with the number of minor "work around" anomalies reported far less frequently than that. On the other hand, essentially all civilian spacecraft events resulting in complete or catastrophic failure are reported within a few days or weeks of their occurrence. In short, the less severe an event, the less likely it is to be reported; thus, the "public record" of spacecraft anomalies is inevitable weighted toward more serious failures.

Anomalies may affect any particular subsystem, in spite of more frequent failure modes with some subsystems than with others. In addition, the interaction of more than one subsystem or event may be responsible for ultimate severity of the anomaly: for example, the loss of INSAT 1A was attributed to both antenna deployment and attitude control system problems. In case of Superbird A, it appears that a problem with an on-board computer memory register precipitated an operator error, however the ultimate cause of the loss was obviously the exhaustion of oxidizing propellant.

The subsystem which is considered responsible for the anomalies discussed below has been determined through the question of "which technical specialty of personnel would probably be leading the team charged with preventing similar occurrences in the future?" The subsystem for which anomalies have been tracked in the Sperber study are:

(1) Launcher
(2) Apogee Kick Motor (AKM)
(3) Telemetry, Command and Ranging (TC & R)
(4) Communications Payload (COMMP/L)
(5) Mechanisms
(6) Attitude Control System (ACS)
(7) Electrical Power Subsystem (EPS)
(8) Reaction Control Subsystem (RCS)
(9) Thermal Control Subsystem (TCS)
(10) Perigee Kick Motor (PKM)

Figure 4 exhibits the proportional distribution of some 355 anomalies occurring on 102 civilian geosynchronous spacecrafts launched through early 1989.

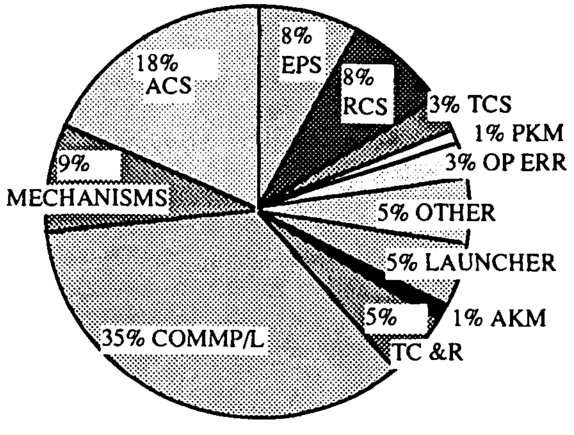

Figure 4 Distribution of 355 reported anomalies by subsystem
Source: CSP Associates Inc

Malfunction of the communications payload was responsible for more reported anomalies than any other cause (i.e., more than one-third). The second most frequent source of anomalies was the attitude control system, followed by the electrical power subsystem and reaction control system.

5. Risk management

5.1 Alternative to the insurance market

The industry has begun to consider additional risk management mechanisms, provided by manufacturers and launch firms. In practical terms, they serve the same purpose: to limit financial exposure through allocation of risk among a number of organizations.

The provision of financial risk management services by manufacturers and launch operators is not a new phenomenon. Indeed, spacecraft manufacturers have provided risk management assistance for many years. This has included provision of pre-ignition insurance as part of the spacecraft production contract, and performance incentives.

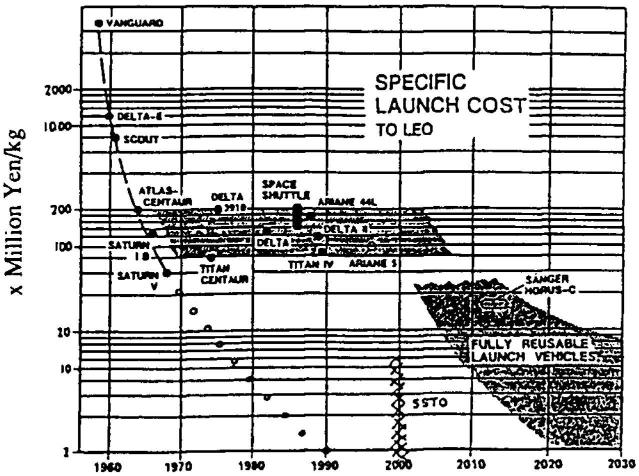

Figure 5 Specific Launch Cost to LEO
Source: Patrick Collins, "ISAS News, No. 138:, September 1992

However, some firms began to ask the satellite manufacturers to become the risk manager for the entire satellite program through on-orbit checkout and delivery. The manufacturer builds the risk management costs into his contract price. Delivery on orbit is one of the few ways in which start-up firms can guarantee total risk coverage in the current environment. The first such contract was signed in 1987, when Hughes Aircraft agreed to provide delivery on orbit for a start-up direct broadcasting venture in the United Kingdom, known as British Satellite Broadcasting (BSB). Delivery on orbit may also be desirable for operators wishing to guarantee predictable (even if expensive) insurance costs[8]).

Launch service companies are currently offering two risks reduction mechanisms: reflight guarantees and indemnification of the value of the launch services. Both are typically paid for by the customer through the payment of a premium on top of the basic price of the launch services. The launch service operators typically cover only the risk created by the launch vehicle, and limit the coverage to the value of the launch vehicle. Hence, the coverage usually terminates with separation of the spacecraft from the launch vehicle, and it does not cover the value of the satellite of business revenues.

5.2 Tasks to be solved by the space industry

What could the space industry do to help the space insurance community ?

Technological development is expected to increase the number of space activities, reduce the cost per pound of delivering a payload into orbit (See Figure 5), develop satellite technology to operate its satellite beyond their design life (See Figure 6) and enhance reliability of future space transportation systems, which will be described in below.

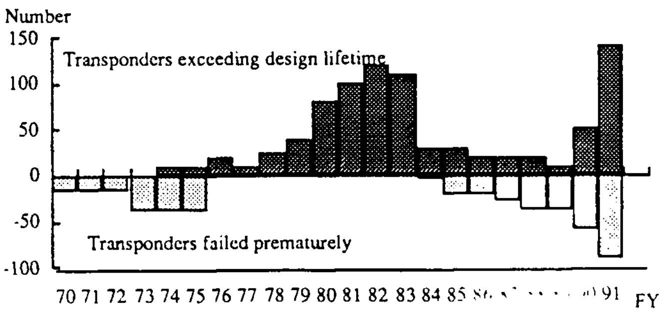

Figure 6 Population of Geostationary Communications Transponder
Source: SPACE MARKET, January 1991

5.2.1 Discussion of future space transportation architecture in Japan

As shown in Figure 5, the way in which cost reductions measures could be vigorously implemented is to approach technology development such as Earth to LEO reusable transportation system, including orbit reentry system.

In July 1993, Future Space Transportation System Study Group which was organized by Science and Technology Agency of Japan announced the vision of space transportation architecture beyond 2000 as follows.

(1) Overview of space infrastructure in the beginning of the 2000's
1) Architecture (space transportation system)
  - Orbital Transfer Vehicle Network through utilization of partly reusable orbital transfer vehicle
  - Expendable launch vehicle
2) Services
  - Implementation of launch services including Space Station
  - Implementation of changeout and retrieval of ORU (On-orbit Replacement Unit)
  - Implementation of space environment utilization and observation

(2) Overview of space infrastructure in 2010-2020 and beyond
1) Architecture (space transportation system)
  - Fully reusable orbital transfer vehicle
  - Partly reusable orbital transfer vehicle
  - Expendable launch vehicle
  - Orbital service vehicle
  - Orbital transportation vehicle
  - Fuel station
2) Services
  - Implementation of launch services at the reduced costs
  - Implementation of large scale space activities, such as Space Station
  - Implementation of changeout and retrieval of ORU
  - Implementation of space environment utilization and observation
  - Sample return from Moon/Planet

5.2.2 Evolution of the U.S. space transportation architecture

As well in Japan, the various agencies of the U.S. government have explored a wide range of options for new space transportation systems for some years. In fact, there are more options under consideration than will ultimately be developed. It is reasonable to suggest a likely path on action, based on those factors which can be predicted with some certainty. The following assumptions seem reasonable[9];

(1) Continuing and large public sector deficits will preclude full scale development of new transportation systems for at least another five years.

(2) Most space transportation planners advocate the continuance of a mixed fleet approach, in which the two fundamental missions are the safe and reliable transport of astronauts and the inexpensive and reliable transport of unmanned cargo. Beyond this, multiple launch options for both manned and unmanned cargo are considered advantageous, but most recognize that the cost for the development and operation of multiple systems (especially manned systems) may be prohibitive.

(3) Existing launch vehicles (ELVs and the Space Shuttle) can meet most, if not all, foreseeable launch requirements for military and civilian space missions for at least the next 10-15 years.

(4) The most important factor which affects future space transportation planning is the expected lifetime of the Space Shuttle. Since it is the only manned space transportation system currently available to the United States, the end of the Shuttle program will set a de facto requirement and schedule for development and operation of a new manned launch system.

(5) There is no critical requirement for new unmanned launch systems, unless the U.S. does commit itself to the manned portion of the Space Exploration Initiative.

(6) At the time when a new transportation system is considered necessary, the preferred option will be based on mature and proven technologies, since the need to maintain continuity of operations will demand low schedule risk and a continuing tight budget will make NASA unwilling to consider options with large technical risk.

Given those assumptions, a fleet of HL20/PLS-type vehicles, combined with today's expendable launch vehicle fleet (with some continuing upgrades and modifications) is the most likely course of evolution.

Assuming that a PLS-type vehicle operations begin at the 2005-2010 period, and that a new unmanned system becomes the next major development priority, it is likely that the PLS-type vehicle would have a lifetime of 15-20 years (i.e. at least until the 2020-2030 period). Thus, the next version of manned transportation system for Earth to LEO operations would probably be defined in the 2015-2020 period.

At this point in time (some 25 years from now), it is likely that SSTO and TSTO concepts will again be considered.

As a good example of engineering development of the next generation space transportation system for SSTO, McDonnell Douglas (MD) succeeded to make its rocket testbed, "Delta Clipper-X (DC-X)" liftoff on 18 August, 1993, through which user can benefit from dramatically inexpensive launch services. This is because fuel costs of DC-X is far less expensive than current launch vehicle with third stage, according to the MD official. DoD will support MD to further development of flight model with about 40 meters in height and 640 tons in mass by as soon as 1998. If development is successful, the rocket can launch payload with up to 10 tons.

Thus, as new fields of space activity is developed toward 2000 and beyond, which will be originated from realization of a new innovative space transportation system, there will be substantial needs for new types of insurance. Demand for insurance will come from the following segments;

(1) Communications satellites owners
(2) Remote sensing system owners (primarily government)
(3) Commercial launch service providers
(4) Man-tended/manned facility operators
(5) Orbit transfer network system organization (including large platform)
(6) Material processing manufacturers

6. Conclusions

In the circumstances where above mentioned new space activities will be emerged, current space insurance market could not provide space industry with risk capacity, and therefore insurance should never be employed as a substitute for a comprehensive risk management plan. Each satellite operator should take the following steps to ensure against the successful satellite launch and operations10);

(1) Request information from launch providers and satellite manufacturers during RFP stage about their success and failure rate
(2) Find ways of giving an advantage to the most successful manufacturer or launch provider in the procurement phase
(3) Impose strict quality control measures during the construction phase
(4) Ensure that engineers supervise the construction phase
(5) Keep abreast of activities at the manufacturer's or launch provider's sub-contractors
(6) Develop an emergency restoration process for use during the operational period of the satellite
(7) Conduct adequate reviews on the satellite frame and subsystems
(8) Exercise supervision over the launch vehicle

Ultimate causes of many on-orbit failures still remain difficult to ascertain. Inadequate telemetry data transmission rates, incomplete records of spacecraft on-orbit component performance and the lack of government support to properly demonstrate immature technologies prior to commercial use, all contribute to recurring failures and often inconclusive corrective measures. The number of catastrophic on-orbit failures should decline, while new procedures in manufacturing, quality control and satellite operations may be expected to mitigate the severity of many partial failures11).

Space insurance is a highly complex subject and in consequence the market usually requires a great deal of technical data. Consequently, governments and firms must cooperate to provide spacecraft information and engineering data or launch vehicle and satellite systems with insurance community so that the insurers could determine more accurately reliability of space activities.

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