Estimating Satellite Insurance Liabilities

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Abstract

Satellite insurance liabilities for a portfolio of direct insurance contracts or facultative reinsurance contracts consist largely of unearned premium liabilities, with relatively smaller contributions from reported and unreported losses. As in life insurance, there is a high probability of loss at launch (birth) and in the early period of operation (infancy), a period of low risk of loss throughout the majority of operation, and a period of high probability of loss towards the end of the satellite's life. This paper describes the risks covered under a satellite policy and discusses the value of using a simulation model based on an active life approach to estimate the expected losses related to a satellite insurance portfolio's unearned exposure. In addition to providing an estimate of the expected losses, such a model allows for the evaluation and incorporation of the benefits from a reinsurance program protecting the portfolio. This model can also be used to estimate the anticipated benefit from reinsurance protections being considered for the portfolio and to price treaty reinsurance contracts.

This paper discusses the concepts underlying the construction of such a model and describes the types of information needed to estimate the model parameters. As part of this discussion, we provide a brief history of the industry and discuss some of the hazards to which satellites are exposed.

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Introduction

Satellite launchings have been with us since the 1950's and have become commonplace. While the earliest satellites orbiting the earth were government owned and funded, over time, privately owned and launched commercial satellites have become the norm. Currently there are hundreds of such satellites in orbit around the planet.

The costs of building and launching a satellite are enormous. Routinely, such costs can be as high as $250 million. Yet, one out of every ten satellites are destroyed by launch failure or fail in the first year of operation. Indeed, recently, the field of satellite launching has seen much increased activity as commercial communication providers attempt to place large constellations of satellites into orbit to create global communication networks.

The high cost of replacement to commercial satellite owners has given rise to a more than a billion dollar a year business for insurers in insuring the successful launch and operation of these costly creations. Currently, some 20 or so insurance entities participate directly in this business. Others participate through reinsurance arrangements with direct providers. The need for a large number of insurers is evident, as most insurance providers have neither the capacity nor the inclination to take on the high potential losses in a single launch. Thus, most launches will have multiple insurers participating.

The Marketplace

Evolution of the Commercial Satellite Industry

From the late 1950's until the early 1980's, the ownership and operation of satellites was generally undertaken only by government agencies like National Aeronautics and Space Administration (NASA) and the European Space Agency (ESA). While commercial satellite insurance has been available since 1964,[1] very little was purchased until the mid 1980's because government agencies generally self-insure the risk. Starting in the early 1980's, the commercial satellite industry began to take off and with it came the increased need for satellite insurance since commercial enterprises are not ordinarily willing to self-insure such high valued assets that are subject to relatively high loss frequencies.[2] Market capacity soared in the 1990's, from around $300 million in 1990 to almost $1.2 billion in 1999,[3] well in excess of the $175 to $250 million of coverage required for most satellites. Occasionally a satellite may require as much as $400 million of coverage.[4]

Satellite insurance is placed through brokers and generally includes multiple insurers on each program. Some reinsurers will accept a number of facultative placements on a risk in addition to the direct line they take on that same risk. As the satellite insurance market has grown, competition and excess capacity have driven rates down, which has led some traditionally self-insured government programs to purchase insurance.

According to an article in Aviation Week & Space Technology, over a thousand commercial satellites are expected to be launched between 1999 and 2008. [5] There are expected to be as many as 150 satellite launches per year by 2008, compared to about 50 launches in 1998. The value of all operating commercial satellites could total $50 billion to $80 billion over the next five years.[6]

Premiums for satellite insurance grew from around $150 million in 1986 to $1,028 million in 1997, dipping to $860 million in 1998. Losses during that same period were erratic, generally less than $100 million per year prior to 1989 and growing to an average of $600 million per year in the last few years, except for 1998 which was an exceptionally bad year for the industry.[7] By May of 1999, more than $1.4 billion had been paid for 1998 claims, with another $500 million reported.[8] In-orbit failures contributed 69% of the 1998 and 31% resulted from launch losses, contrary to the expectation that most losses occur during launch.[9] The distribution of 1998 losses to launch and in orbit (INO) losses is partly reflective of the growing number of insured satellites that are already in orbit. Further, as of August 1999, estimated losses for 1998 and 1999 combined exceed $2.25 billion, well in excess of premiums of $1.37 billion for the period.

So, we see that the satellite insurance industry was profitable for the 20 years ending with 1998,[10] but that profit margins have declined as rates have fallen over the last few years. Indeed, in 1997, rates averaged around 16% of the insured values and generally offered coverage for launch plus a year of in-orbit coverage. In 1998, rates dropped to 11% and in-orbit coverage increased to 5 years on many programs. The decrease continued in 1999, when rates of 7% could be negotiated, where the lowest rates were offered on policies providing less than 5 years of in-orbit protection.[11] There was not a proportionate reduction in exposure as the rates declined.

The poor experience in 1998 and 1999 will likely drive rates up, but it will probably take more than a year before the impact materializes as many launches are committed to in advance at current rate levels.[12] Some underwriters feel that rates must increase to around 15%, or double the May 1999 level, in order to make a profit.[13] This situation may be exacerbated by recent restrictions imposed by the State Department's "International Traffic in Arms Regulations" which have significantly slowed the flow of information to overseas underwriters. This could in turn be a deterrent to effective underwriting and pricing.[14]

Satellite Insurance Liabilities

Satellite insurance liabilities for a portfolio of direct insurance contracts or reinsurance contracts fall into two classes. First, there are liabilities for losses that have already occurred. For reasons we discuss later this is likely to be a small part of the total exposure. The largest exposure to liabilities generally is related to the unearned premium for launches committed to that haven't occurred yet as well as for satellites that are currently in orbit who's performance is being guaranteed. Given the potential for catastrophic loss, the authors believe that proper evaluation of the profit/loss potential of the unearned premium reserves (UPR) should be studied intensely. This in turn requires consideration of the portfolio's actual exposure to loss.

Satellite mortality is very similar to human mortality in that there is a high frequency of loss at launch (birth) and in the early stages of operation (first year). This is followed by a long period of operation in which there is a low probability of loss. Finally, there is a period of increased risk of failure towards the end of the satellite's design life.

Causes of Satellite Failure

Launch

1998 aside, the most significant hazard affecting satellites is the launch itself. A failed launch may be due to explosion of the launch vehicle or the failure to deploy the satellite into a usable orbit. Launch failure has historically represented the greatest probability of loss and about seven per cent of satellites have failed on launch.

Post Separation and In Orbit losses

While launch represents the greatest probability of failure satellite failures can occur at any time during orbital life. Such failures may result in a total loss of functionality or may be partial, where the satellite continues to operate but at a diminished capacity or reduced expected life.

Immediately following the successful deployment of a satellite into a usable orbit there is a roughly 5% probability that the satellite will experience a total or partial failure in the first six to 12 months of its life. This period is referred to as the Post Separation Phase (PSP). While orbital losses most frequently occur during the post separation phase they can occur in the later years of operation as well.

If the satellite survives PSP it enters the in-orbit or INO phase and the probability of failure is much diminished in any one year. Indeed, once in orbit, many satellites operate for periods that are years in excess of their expected useful life. Still, unexpected total or partial failure may occur at any time.

The causes of orbital failure, PSP or INO, are varied. Obviously, systems will fail from time to time and, if their function cannot be replaced by built-in redundancies, there will be a loss. However other dangers exist in the wilds of space. These include:

Electrostatic Discharge

The most prevalent post-separation/in-orbit hazard to a satellite is electrostatic discharge, which can be induced by solar activity or by the formation of plasma clouds due to the ionization of meteoroids colliding with a satellite.[15]

Loss of Fuel

Satellites carry a certain amount of fuel with them. Such fuel is needed to keep the satellite orbiting in the required path. However, the fuel supply may be consumed at a faster rate than anticipated, if for example, an initial amount was spent in putting the satellite into its useful orbit. Such a situation might be deemed a partial failure as the useful life of the satellite is now expected to be reduced.

Solar Storms

Solar storms can interfere with the proper functioning of a satellite's electrical components and can affect satellites over a large percentage of the sky. The magnetic activity associated with solar storms can induce electrostatic discharges that can cause satellites to malfunction. Solar storms can also cause warm air to rise, dragging low-earth-orbit satellites into lower orbits and forcing the operators to use onboard fuel to reposition the satellite, potentially shortening its life. Numerous recorded anomalies are thought to be attributable to solar storms.[16] Only one insured loss is believed to be attributable to anomalies induced by solar storms (Telstar 401).[17]

Concerns about the catastrophic failure of multiple geosynchronous satellites in close proximity due to pockets of intense magnetic activity in solar storms cause some insurers to limit their exposure within orbital arcs of a selected size, say 3-5°. Because solar storms can last more than a day, all geosynchronous satellites may be exposed to a single solar storm as the earth rotates.

Meteor Showers

Meteor showers represent a source of risk for satellites. It is believed that a meteoroid destroyed the European Space Agency satellite Olympus in 1993. Meteor showers occur regularly, so satellite operators are able to preemptively reorient solar arrays to reduce the risk of damage.[18] Meteors present more risk to satellites in geosynchronous orbits than to satellites in low earth orbits, which are protected somewhat from meteors by the earth's atmosphere even though it is very thin at these altitudes.

Collisions with Space Debris

Satellites in low earth orbit are exposed to losses from collisions with space debris. There have been numerous incidents of space debris colliding with and damaging windows on the space shuttle,[19] including one in which a small fleck of debris punched halfway through the window of the space shuttle Discovery. The satellite Cerise was lost when it collided with a discarded Ariane rocket body, making it the only recorded insurance loss from a collision with space debris.[20] Because of the high velocities with which objects in orbit travel, a collision with even the smallest particle of space debris could destroy a satellite.

Electromagnetic Interference

Placing satellites too close together can cause degradation in the observed operation of a satellite due to electromagnetic interference from a neighbor. Currently, a restriction forbids satellites from being placed closer than 1.5° of orbital arc from each other. Electromagnetic interference is not necessarily an insured loss because it is not a failure of the satellite.

Salvage Potential

There is generally no opportunity for salvage related to satellite losses. There are circumstances, however, where salvage is possible if a satellite declared to be a total loss can still operate at a reduced capacity. In these relatively rare situations, it could be economically advantageous for the original owner/operator to buy back the damaged satellite and make use of its reduced capacity. For example, the satellite may still have some functioning transponders or may be fully functional for a fraction of its original design life. In these cases, the satellite operator may wish to return some of the insurance recovery in exchange for the remaining capabilities of the satellite.

Following a failed launch in late 1997 that led to a total loss covered by the insurance industry, Hughes Global Services in May/June 1998 successfully repositioned the HGS-1 satellite (formerly Asiasat 3) into a usable geosynchronous orbit with enough fuel remaining to provide 10 to 15 years of service.[21] Successfully repositioned, HGS-1 will be available to provide communications services for government agencies and private customers;[22] a proportion of the proceeds will be shared with the insurance industry. While this kind of salvage opportunity can not be guaranteed and will not always be economically feasible, it is an example of the potential for significant salvage opportunities. It may also be possible to obtain salvage associated with ground based equipment rendered useless by the failure of a satellite.

ACTUARIAL CONSIDERATIONS

Types of Reserves

The UPR contributes the majority of the reserves held for a satellite portfolio, but there are smaller contributions required for reported and IBNR claims. While the discussion below focuses the liabilities related to the UPR, we will briefly discuss the case and IBNR reserves.

Reported and Development on Reported

As in all lines of insurance, case reserves are carried for all reported but unpaid claims. While reporting and settlement of claims is quite rapid in satellite insurance, there is development on reported claims. The time frame for this development is fairly short and the aggregate amount of the development tends to be small. We have seen that claims occasionally show small movement beyond 24 months from the date of first reserve. Development on case reserves can be estimated using standard report year techniques. Because of the low frequency of events in a given year and the almost instantaneous knowledge of catastrophic events, one should consider arranging data by report day or month if losses occurring during a year are non-uniformly distributed in time.

Pipeline IBNR

An insurer may know about a loss before it is actually reported. Because the industry involves a relatively small number of very valuable risks, a loss is often reported publicly before it is reported through insurance channels with the required documentation. Many losses occur during launch, are covered by the media and tend to be quite spectacular. In these instances, an insurer will know very quickly that a total loss will soon be reported and should post a reserve accordingly.

Orbiting satellites frequently develop anomalies that are discovered during their routine diagnostics. Most often these anomalies do not develop into losses because they disappear or are corrected or bypassed through a built-in redundancy. The loss of redundancy is generally not considered an insured loss. If an anomaly develops into a loss, the severity of the loss may not be known immediately. In these instances, an insurer may reasonably anticipate that a loss is coming and should record a reserve equal to their best estimate of the magnitude of the loss. The loss may not be reported until the occurrence and severity of the loss can be assessed, which could be a matter of several months or longer.

True IBNR

Most direct losses are known, reported and paid within a very short period of time. Reinsurers, however, may experience reporting delays for losses on which they have no direct placement, which leads to the necessity to carry an IBNR reserve. We have found that, in practice, some pure IBNR may be necessary, although the amounts tend to be small because of the rapid reporting and payment patterns of major events. This may be particularly true if coverage adheres as excess reinsurance where some reporting delay may be expected. The required true IBNR can be assessed using standard accident year analysis and evaluations of historical reporting patterns, neither of which will be discussed in this paper. In estimating true IBNR, care must be taken not to double count the development on case or pipeline IBNR if separate estimates are made of these liabilities.

Unearned Premium

Unearned premium reserves are by far the most significant contributors to the reserves recorded for active satellite insurers. Because the contracts covering launches are often written well in advance of the actual launch, premium collection and earning for these contracts may not occur for quite some time, often years. As such, an insurer may carry a large unearned premium reserve on their books. To the extent that the premiums are uncollected, the company may also carry an offsetting premiums receivable asset. The profitability associated with unearned premium should consider both the adequacy of the unearned premium reserve for insured satellites currently in orbit as well as the adequacy of premiums committed to for future launches.

Carried UPR

The premium written for satellite insurance is usually not broken out into launch, post-separation and in-orbit components. It is reasonable to earn premium over each of these periods, and this is the approach we have seen in practice. (We note that there may be other approaches to the earning of premium that are utilized.) Because the earning patterns differ for the three periods, the premium must be allocated to each applicable period. There is no standard procedure for allocating the premium, but a reasonable approach is to distribute the written premium to launch, PSP and INO in proportion to the corresponding rates developed while underwriting the policy. These rates may or may not sum to the overall rate ultimately accepted for the policy. Once premium is allocated to the various exposure periods, a company's earning routine will determine the unearned premium as of any valuation date.

Launch premiums are earned upon completion of a launch. Post-separation and in-orbit premiums are earned over the duration of the periods defined in the policy. If a total loss occurs, all unearned premium should be immediately earned. If a partial loss occurs, the unearned premium should be earned in proportion to the severity of the loss. While it is reasonable to earn the PSP and INO premiums uniformly over the duration of the exposure periods, there is some logic for earning the bulk of the PSP premium in the first 60 to 90 days because that is the period during which most orbital losses occur.

The UPR may be insufficient to cover the related losses for a number of reasons. The written premiums may be inadequate to cover the associated losses, which is a recent concern due to the low rates and high losses plaguing the industry over the last few years. The premium may not have been appropriately allocated to coverage period. If too much premium is allocated to the launch period, the premium will earn too quickly, causing the UPR to be inadequate even if the total written premium is adequate.

Regardless of how the premium is allocated and earned, it is important to know if the UPR is adequate to cover the associated losses and how much profit or loss can be expected to be derived from the UPR. For this task we employ an exposure model that, in addition to allowing us to evaluate the adequacy of the UPR, enables us to determine confidence intervals within which unearned profits are likely to fall. Our model also permits us to evaluate the impact of placed or proposed reinsurance programs on the estimated liabilities and the corresponding profits.

Modeling Losses Related to Unearned Satellite Exposures

In the remainder of this paper we outline a model that we have built to analyze unearned space exposure. The model has a variety of uses. These include estimating the net profitability of an unearned premium reserve, estimating the effects of reinsurance on such an exposure, evaluating the efficacy of competing reinsurance programs and pricing a book of satellite exposure. Our model is a simulation model and considers satellite insurance as an active life type of exposure in that the exposure takes place over a many year period and that the probability of loss changes with time. Like active life reserving we consider both premium income flows and loss and expense outgo flows. However, more akin to property casualty exposures, in that the largest number of exposures will have no loss associated with them.

In our model we simulate the loss experience of a satellite using a discrete distribution to describe the probability of loss events, the dates of the simulated losses, and the severity of the loss (needed for partial losses only). For post-separation and in-orbit periods, the distribution allows for the possibility of both total and partial losses. (We note that for simplicity we have not incorporated an allowance for multiple partial losses or partial losses followed by a total loss for a given satellite as such multiple events would be rare and relatively insignificant). During each simulation, we generate the loss experience individually for all satellites exposing a portfolio, after which we attach the insurance coverage offered by the portfolio. Having simulated the losses incurred by a portfolio, we determine the benefit from any placed or proposed reinsurance program. We repeat this process thousands of times in order to generate credible statistics for the aggregate losses incurred by the portfolio, both gross and net of reinsurance. In our model we produce results on a nominal and discounted basis.

The most difficult part of creating the simulation model is constructing the probability distributions of launch, PSP and INO failure.

Use of Historical Information

As in all actuarial estimations, the history of losses in the satellite industry is an important guide in predicting future losses associated with a portfolio. Parameters representing the propensities for loss in satellite insurance are subject to significant judgement and are influenced more by recent history than long term history. For satellites already in orbit, the current health of the satellite is the best indicator of the risk of a future failure.

Information on the rate and type of failures and anomalies for satellites and launch vehicles can be obtained from many publicly accessible sources as well as from commercially available compilations. Airclaims Spacetrak and BH Associates are two firms that compile and market information related to satellite launches and operations, including information on anomalies and failures. A significant amount of information is available on the Internet regarding past and future launch activity. Most satellite and launch vehicle manufacturers and operators have web sites, some of which provide current information that is helpful in determining probabilities of loss. Brokers placing satellite insurance often provide information on failure rates and specific information relating to the individual risks being placed, including the history of anomalies and the latest diagnostics for satellites.

Because most losses occur during launch, the reliability of the launch vehicle used to deploy a satellite can significantly impact the expected losses and the corresponding cost of insurance. Of the commercial launch providers, Arianespace has the largest market share, a position they obtained when the American launch industry became temporarily committed solely to space shuttle deployments in the early eighties, only to be interrupted with the explosion of the Space Shuttle Challenger. There is now fierce competition among launch providers on all continents. The recent joint venture Sea Launch successfully placed a test payload into orbit, adding itself to the competition to provide launch services. Many competitors continue to develop and employ new launch technologies capable of delivering heavier satellites or multiple payloads. New launch vehicles often suffer early losses but are usually expected to perform well after their systems and technologies are debugged and improved, so their short failure history is not necessarily an indicator of expected future performance. Because of this, data needs to be continuously updated to be sure that estimates of launch failure are up-to-date.

The frequent introduction of new technologies and the improvement of existing technologies introduces the need for significant judgmental adjustments to the selected loss propensities. For example, several new launch vehicles, Ariane 5 and Delta III for example, have been introduced in the last few years. Each of these launch vehicles suffered losses in their maiden flights, but both are products of highly respected manufacturers and might be expected to be reliable launch vehicles in the future. Ariane 5 has had several successful subsequent launches. In these circumstances, it is prudent to judgmentally select loss frequencies lower than the historical loss frequencies (100% for Delta III and 25% for Ariane 5). It is likely that the experience of such highly technical products will significantly improve as defects are identified and corrected.

Launch Failure Frequency

We selected the probabilities of failure by launch vehicle based on historical performance. We tabulated the frequency of loss over the last five years, the last ten years and for the entire history of each launch vehicle's service. We based our frequencies of launch failure on these statistics, grouping related launch vehicles together where appropriate in order to increase credibility. We judgmentally adjusted the probabilities if we deemed recent launch statistics to be more relevant than statistics from older years. For example, we chose lower loss frequencies than observed in the historical performances for Ariane 5, Delta III and Long March 3B, all of which suffered losses in their maiden flights but are expected to perform better on future launches. Early losses and limited loss histories combined to produce unrealistically high loss frequencies, which we judgmentally lowered. In coming to conclusions as to what we believed were appropriate probabilities of loss by rocket, we spoke with space underwriters who were knowledgeable of the differences in rocket technology. Thus, we were able to incorporate a prospective point of view into our computations as well.

Occasionally, the launch vehicle is not uniquely specified for a contract. This complicates the pricing process since the probability of launch failure depends on the rocket used. If the launch vehicle is not specified or there are several possible launch vehicles, we use either an average loss frequency or the loss frequency for the launch vehicle most likely to be used.

Credibility Considerations

In addition to the propensity of individual rocket loss probabilities to change over time, credibility is a particularly keen consideration for this line. With only a handful of rocket launches for each type of rocket, it is clear that we don't have enough observations to draw definitive conclusions about any specific model of launch vehicle. Indeed, even the most popular of launch vehicles would have only small partial credibility by traditional definitions.

Credibility is somewhat heightened because the great bulk of the losses (at least by dollar measurement) are total losses. The distribution of losses for an individual rocket launch is thus a binomial distribution (i.e., the rocket launch is successful or not and, the amount of any loss is fixed). With no need to consider severity as a factor (its determined as the sum insured) credibility improves. Still, even considering all the launch failures in history in total, there is limited credibility.

For this reason, after selecting probabilities of launch failure by vehicle, we calculated the historical frequency of failure in total for all launch vehicles and adjusted our probabilities of failure by launch vehicle so as to balance back to our computations in total. In this way we believe that we have accounted for differences in launch failure rates by vehicle but improved our estimation process by incorporating maximum credibility.

It is interesting to note that we performed a fair amount of analysis on the probability of launch failure over the last 30 years. Our analysis indicated that, while there appear to be differing probabilities of loss by rocket, the average probability of rocket launch failure has not dramatically changed over the last 20 years.

Post-separation and In-Orbit Failure Frequency

We based our estimates of the frequency and severity of commissioning and in-orbit failures on the historical failure statistics for satellites that achieved successful orbits.

Prior to its launch, the expected frequency of failure for a satellite, assuming it survives the launch, can be estimated from the history and character of anomalies and failures associated with similar satellites already in orbit. By similar satellites we refer to satellites built on the same bus with similar payloads. The historical loss frequencies should be judgmentally adjusted if it is known that the cause of an anomaly/failure has been rectified in the design of the bus or payload. The severity of a loss, given that one is simulated, should be estimated based on the severity of prior losses for similar satellites.

For satellites already in orbit, the best predictor of future losses is the current health of the satellite. Diagnostics are routinely run on satellites and reports are made on the nature and status of all anomalies. The results of these diagnostics, as well as the past performance of similar satellites, can be used to judgmentally determine the likelihood of failure for a particular satellite.

In principle, the above process could be undertaken to formulate estimates of the probability of failure for each satellite covered by a portfolio. However, estimating meaningful failure frequencies by satellite requires significant technical expertise to interpret the various anomaly reports and continuous up-to-date knowledge regarding the state of the art in satellite manufacturing. Additionally, loss data relating to satellites of various designs has little credibility due to its limited volume. As such, we relied on the aggregate loss history for all satellites to estimate loss frequencies by year of satellite life and applied these frequencies to all satellites uniformly.

We selected probabilities of loss by age of satellite based on the historical performance of all satellites following an active life approach. For all satellites successfully placed into orbit since 1980, we compiled the date of launch, the date of failure (if applicable), the date of retirement (if applicable) and the current status. For each year of a satellite's life, we calculated indicated conditional probabilities of failure as the ratio of the number of failures in the year to the number of satellites that were operational at the beginning of the year, where the year refers to the age of a satellite.

Probability of Failure by Year

The calculation of the probability of failure by year differs depending on whether the satellite has already been launched. For satellites that are already in orbit, we simulate loss dates relative to the day on which we run the simulation. Since the age of any orbiting satellite on the date of simulation is not likely to be an exact number of calendar years, we use an interpolative procedure to adjust the conditional probabilities appropriately. For satellites that have not been launched, no interpolation is needed.

For satellites that are yet to be launched, we determined the probability of satellite failure during launch and during each year following launch. The probability of failure during a given year is the product of the probability that the satellite survives to the beginning of the year times the conditional probability of failure during the year, as given by our selected conditional probabilities.

This procedure generates a discrete probability distribution of failure for each satellite, depending on its age and launch status. These probability distributions drive our simulation model.

Severity

We consider all launch failures to be total losses. We allow for the possibility of both partial and total losses in the post-separation and in-orbit periods. We estimated that post separation and in-orbit losses are partial losses 60% of the time and total losses 40% of the time. For partial losses, we assume that severities of 15%, 30% and 45% are equally likely. These are very judgmental assumptions based on the limited amount of data available. We did not allow for salvage in our estimates.

Date of Loss

The distributions derived above allow us to simulate the severity of a loss and year of that loss. We assume that losses are equally likely to occur within a year, so we randomly generate the day within the year on which the loss occurs.

Launch Manifest

We simulate losses for all satellites exposing the portfolio. For each satellite, we must have the following information:

1. Satellites Name
2. Date of Launch
3. Launch Vehicle

We need this information even for satellites which have already been launched because it is used to calculate the age of the satellite, which determines which conditional probabilities are used. The following table shows a partial launch manifest for the example portfolio described below.

Partial Launch Manifest
As of April 1, 2000

Future Launches

Satellite	Launch Vehicle	Launch Date	Age
EURASIASAT 1	ARIANE 5	April 1, 2000	0.00
NSS-6	ATLAS IIA	June 30, 2000	0.00
TELESAT ANIK F1	ARIANE 44L	July 1, 2000	0.00
EUROPESTAR 1	ARIANE 44LP	July 6, 2000	0.00
PANAMSAT 1R	ARIANE 5	July 31, 2000	0.00
Quickbird 2	START 1 (SL-18)	December 1, 2000	0.00
L STAR 1	ARIANE 4	June 1, 2001	0.00
BRASILSAT B5	ARIANE 44LP	October 30, 2001	0.00
IRIDIUM LM10	LONG MARCH 2C/SD	December 1, 2002	0.00
IRIDIUM LM11	LONG MARCH 2C/SD	December 1, 2003	0.00
.	.	.	.
.	.	.	.
.	.	.	.

Already Launched

Satellite	Launch Vehicle	Launch Date	Age
ASTRA 1A	ARIANE 44LP	December 11, 1988	11.31
GALAXY 6	ARIANE 44L	October 12, 1990	9.48
SATCOM C1	ARIANE 44P	November 20, 1990	9.37
INTELSAT 703	ATLAS IIAS	October 6, 1994	5.49
MEGSAT	COSMOS 3M	April 28, 1999	0.93
TELSTAR 7	ARIANE 42LP	September 25, 1999	0.52
GARUDA 1	PROTON D-1-E	February 12, 2000	0.13
.	.	.	.
.	.	.	.
.	.	.	.

With this information and the loss probabilities discussed above, we can simulate losses for every satellite in the portfolio. There are frequent changes to the launch schedules, and the launch vehicle is not always known and occasionally changes. Keeping launch information current is vital to the model. Changes in the launch manifest can be found in numerous sources on the Internet and is also available from several compilations commercially available.

Attachment of Coverage

Our model simulates failures for each satellite to which the portfolio is exposed. Given a simulated failure, the model attaches all applicable insurance contracts to the loss. Accordingly, the following information is needed for each policy in the portfolio:

1. Policy number
2. Underwriting year
3. Insured satellite
4. Coverages offered (Launch, post-separation, in-orbit)
5. PSP and INO period and/or duration
6. Signed or written status
7. Sum insured
8. Policy inception and expiration dates

The following table shows a partial listing of a possible portfolio with the necessary information for each policy or contract.

Sample Selection of Contracts from a Portfolio

Future Launches

Policy/ Contract	*Type of Policy*	*UW Year*	*Satellite*	*Date of Launch*	*Coverages*	*PSP Duration*	*INO Duration*	*Signed/ Written*	*Sum Insured*	*Effective Date*	*Expiration Date*
Policy 1	Direct	2000	NSS-6	06/30/00	Launch/PSP/INO	12	48	Signed	1,000,000	January 1, 2000	December 31, 2004
Policy 2	Facultative	1999	NSS-6	06/30/00	Launch/PSP/INO	6	30	Signed	2,000,000	June 1, 1999	May 31, 2003
Policy 3	Facultative	1999	NSS-6	06/30/00	Launch/PSP	12	0	Signed	1,200,000	March 1, 1999	February 28, 2003
Policy 4	Facultative	1999	NSS-6	06/30/00	Launch	0	0	Written	3,000,000	August 13, 1999	August 12, 2002
Policy 5	Direct	2000	TELESAT ANIK F1	07/01/00	Launch/PSP/INO	12	36	Signed	1,500,000	February 15, 2000	February 14, 2004
Policy 6	Direct	2000	EUROPESTAR I	07/06/00	Launch/PSP/INO	6	54	Written	10,000,000	March 20, 2000	March 19, 2004
Policy 7	Facultative	1998	PANAMSAT IR	07/31/00	Launch/PSP/INO	12	24	Signed	500,000	December 21, 1998	December 20, 2002
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.	.	.	.	.	.	.	.	.	.	.	.
Policy 28	Direct	1998	Quickbird 2	12/01/00	Launch	0	0	Signed	750,000	March 15, 1998	March 14, 2002
Policy 29	Facultative	2000	Quickbird 2	12/01/00	Launch/PSP/INO	12	36	Signed	5,000,000	February 15, 2000	February 14, 2002
Policy 30	Facultative	1999	L STAR I	06/01/01	Launch/PSP/INO	12	36	Signed	3,000,000	June 15, 1999	June 14, 2003
Policy 31	Facultative	2000	BRASILSAT B5	10/30/01	Launch/PSP/INO	6	54	Signed	15,000,000	January 13, 2000	January 12, 2005
Policy 32	Direct	1998	IRIDIUM LM10	12/01/02	Launch	0	0	Written	300,000	May 3, 1998	May 2, 2003
Policy 33	Direct	1999	IRIDIUM LM11	12/01/03	Launch	0	0	Signed	3,000,000	February 1, 1999	January 31, 2004

Already Launched

Policy/ Contract	*Type of Policy*	*UW Year*	*Satellite*	*Date of Launch*	*Coverages*	*PSP Duration*	*INO Duration*	*Signed/ Written*	*Sum Insured*	*Effective Date*	*Expiration Date*
Policy 114	Direct	1999	ASTRA 1A	12/11/88	INO	0	24	Signed	2,000,000	July 15, 1999	July 14, 2001
Policy 115	Direct	1998	GALAXY 6	10/12/90	INO	0	36	Signed	100,000	March 1, 1998	February 28, 2001
Policy 116	Direct	1999	SATCOM C1	11/20/90	INO	0	48	Signed	10,000,000	April 25, 1999	April 24, 2003
Policy 117	Direct	2000	INTELSAT 703	10/06/94	INO	0	36	Signed	3,000,000	January 1, 2000	December 31, 2002
Policy 118	Facultative	1999	INTELSAT 703	10/06/94	INO	0	24	Signed	5,000,000	July 1, 1999	June 30, 2001
Policy 119	Facultative	1999	INTELSAT 703	10/06/94	INO	0	24	Signed	750,000	July 1, 1999	June 30, 2001
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Policy 220	Direct	1999	MEGSAT	04/28/99	Launch/PSP/INO	12	36	Signed	1,250,000	March 11, 1999	March 10, 2004
Policy 221	Direct	1998	TELSTAR 7	09/25/99	Launch/PSP/INO	6	30	Signed	15,000,000	July 1, 1998	June 30, 2001
Policy 222	Direct	1998	TELSTAR 7	09/25/99	Launch/PSP/INO	12	24	Signed	3,000,000	July 1, 1998	June 30, 2001
Policy 223	Direct	1998	TELSTAR 7	09/25/99	Launch/PSP	12	0	Signed	2,500,000	July 1, 1998	June 30, 2001
Policy 224	Direct	1998	GARUDA 1	02/12/00	Launch/PSP/INO	6	42	Signed	10,000,000	May 15, 1998	May 14, 2003
Policy 225	Direct	2000	EURASIASAT 1	04/01/00	Launch/PSP	12	0	Signed	4,000,000	February 20, 2000	February 19, 2002

Note that several satellites expose multiple policies or contracts. Since the terms for contracts covering the same satellite may differ, it is important check that coverage is in-force and applicable for each contract exposed to a satellite for which we simulate a loss.

The dates of coverage are needed to determine if the policy is in force at the time of the simulated loss. For policies covering launches which have not yet occurred, the policy inception and policy expiration dates determine the time frame within which a launch must occur in order for the policy to be enforceable. While we do not account for it in our model, it is reasonable to simulate launch delays which could result in launches occurring outside of this time frame, which would nullify the coverage.

The sum insured specifies the amount of coverage. Before attaching a policy's coverage, a number of adjustments may be necessary to the sum insured, as described below.

Re-Flight Guarantees

Some launch providers offer reflight guarantees, which means that they will provide a second launch at no charge in the event of a launch failure. If there is a reflight guarantee, the sum insured during the launch phase will be less than the sum insured during the PSP and INO phases, where the cost of the launch will be included in the sum insured.

Depreciation

Insured amounts may also change over time due to the depreciation in the value of the satellites. If applicable, the depreciation schedule will be defined in the contract. For in-orbit coverages, we depreciated the sum insured according to how far into the policy period the loss occurred. If we did not know the depreciation schedule, we assumed a 10% annual depreciation.

Adjustment for Partial Losses

We adjust the sums insured for known losses if the contract parameters do not already reflect the loss. For known partial losses, we reduce the sums insured in proportion to the partial loss. For known total losses, we set the sums insured to $0 for contracts covering those satellites, which should be redundant because we do not include failed satellites in the simulation.

Adjustment for Written but Unsigned Contracts

Policies are not always bound at the coverage amounts originally offered. If a company books unearned premiums for contracts that will be bound for as yet undetermined coverage amounts, they should adjust the booked premium to reflect the difference between the written line and the expected signed line. The same adjustment must also be made to the sums insured before estimating the liabilities associated with these contracts. We base these adjustments on specific advice from brokers or on the historical relationship between the written and signed lines if no such advice is available.

Multiple Contracts Covering a Single Satellite

Having simulated losses and adjusted the sums insured, we attach the portfolio to the simulated losses. Because each satellite may be covered by multiple contracts with different coverage periods, we simulated a date of loss and compared it to the coverage expiration date for each applicable policy. Any policy that was expired as of the simulated loss date did not contribute to the liabilities.

Discounting

We discounted losses at a 5% rate using the simulated loss dates and any reporting/payment delays applicable.

Reinsurance considerations

Quota Share Reinsurance

Accounting for the effect of quota share reinsurance on the satellite liabilities is straightforward and merely requires the application of the appropriate quota share percentages. Expenses and commissions of various types must also be considered when estimating the impact on profitability.

XOL programs

One of the key benefits of using a simulation model to estimate satellite liabilities is that it allows you to incorporate an existing or proposed excess of loss (XOL) reinsurance program. Estimating the effect of XOL programs on the expected aggregate losses is conceptually straightforward but can be a difficult to program.

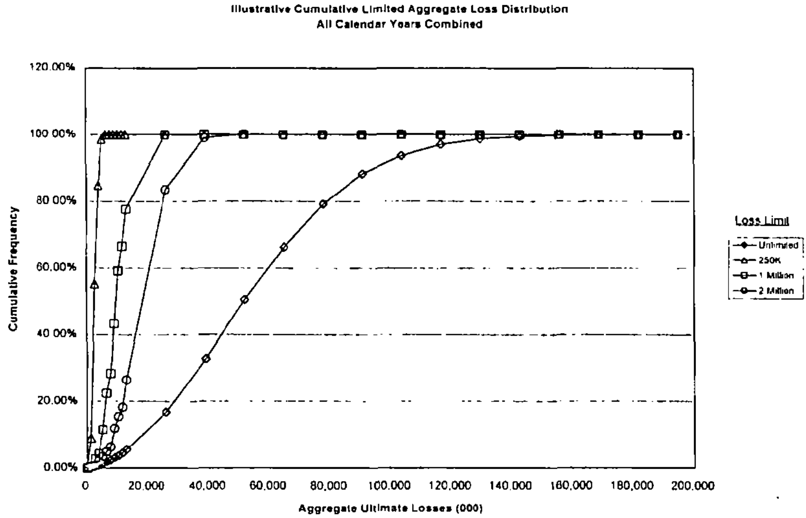
Determining the coverage provided by an XOL program requires tabulating the size and date of the individual losses generated during each simulation. The size of the loss refers to the combined contribution to the incurred losses made by all policies triggered by the failure of a specific satellite. We arrange all of the losses from a simulation in the order of their simulated loss dates and cumulate the affect of the XOL program. This requires that we monitor:

1. Attachment points
2. Limits and their erosion
3. Aggregate retentions and their erosion (including inner aggregates for layers where appropriate)
4. Reinstatement premiums

The various attachment points, retentions, limits and reinstatement premiums may change by calendar year if the program is defined for multiple years. The various program parameters must be reset at the beginning of each calendar year if the coverage is written on a calendar year "losses occurring" basis.

Results

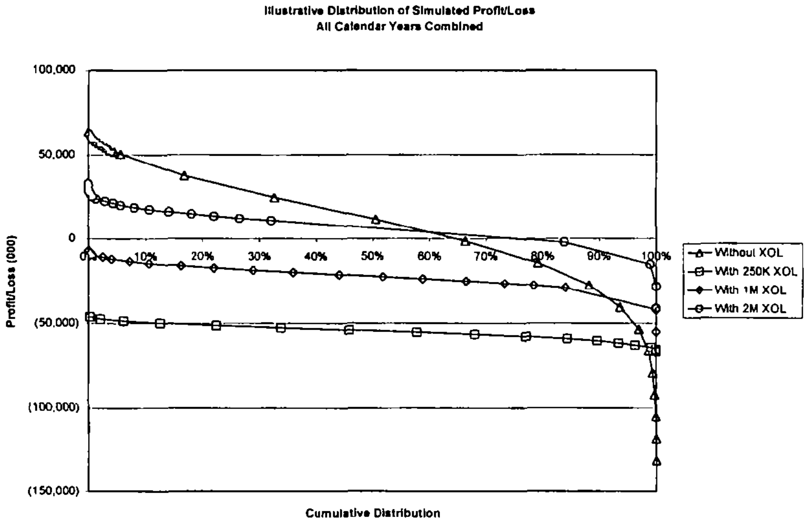
Having captured the information as described above, we run our simulation many times and estimate the expected losses related to the portfolio and their variance. The following chart shows a sample distribution of aggregate losses generated by our model.



This exhibit shows the estimated distribution of losses without consideration of XOL protection as well as the distribution of aggregate retained losses considering the benefit XOL reinsurance attaching at three different attachment points. The mean results can be used as point estimates for the expected losses associated with the unearned portion of the premiums. The variability in the aggregate losses resulting from our simulations can be used to calculate ranges within which the aggregate losses can be expected to fall at various levels of confidence. In addition to the loss components, provisions must also be added for anticipated expenses, including any contingent commission or profit provisions associated with the reinsurance programs.

Our results can be considered a measure of the adequacy of the booked unearned premium reserves and can be used to determine the need to book additional reserves due to regulatory requirements related to long duration contracts, if applicable.

In addition to determining the expected losses and reserve requirements, these results can be used to evaluate the expected profitability in the unearned premium reserve and the possible volatility of the profits. The following chart shows a typical distribution of expected profits, both with and without the protection of XOL programs with three different attachment points.



In this example, there is a wide variation in possible results, from very profitable to catastrophically unprofitable. In the example given, all of the XOL programs flatten out the variability in the results, but it is clear that the program with the higher attachment point is the most advantageous of the three with the given pricing. The program with the highest attachment point is the only one of the three programs that appears to offer a benefit comparable to or better than retaining the exposure in total. For the program with the lowest attachment point, there would only be a benefit under the most catastrophic of scenarios.

Additional Uses

In addition to evaluating the liabilities stemming from a company's portfolio of direct and facultative reinsurance contracts, our model can also be used to price an XOL program being offered by a company. In this circumstance, the portfolio of the ceding company should be programmed and the proposed XOL program will be that of the assuming company. The relevant output in this circumstance is the XOL recoveries predicted by the model. The same model can also be used to evaluate the liabilities expected to result from a placed XOL program.

Modifications

There are a number of modifications that can be made to improve performance of the model. Simulated launch delays could be included, which would allow for the possibility of policy expiration prior to the launch. Probabilities of PSP and INO failure could be estimated for each satellite by incorporating information from the diagnostic reports and other satellites specific information. Rather than only allowing partial losses of 15%, 30% and 45%, we could allow for a continuous spectrum of severities. Where we assume annual depreciation of 10%, the actual depreciation schedules could be used.

Caveats

The discussions above are solely the opinions of the authors and not necessarily those of their employers or clients. We note that actuarial projections involve an estimation process and may indicate results that vary materially from actual experience. The examples and exhibits contained in this paper are illustrative only, and are not intended to represent any real life situation.

Glossary

Many of the terms used in satellite insurance are not common to actuarial work, so we include this section to define some of the terms that we will use throughout this paper.

Geosynchronous orbits (GEO) are high earth orbits (22,237 miles) around the equator at which a satellite's relative position to the earth remains fixed.

A **low earth orbit (LEO)** is an orbit with an altitude of between 200 and 300 kilometers (62 to 124 miles).

A **constellation** is a network of satellites placed into low earth orbit and arranged into a configuration that permits global mobile telephony and data services. These can consist of large numbers of satellites and have contributed significantly to the growth in the commercial satellite industry and the corresponding growth in the insurance market.

The **launch vehicle** is the rocket used to inject a satellite into orbit.

Launch coverage refers to the coverage for the period during which a satellite is lifted into a usable orbit. A launch is deemed successful once the satellite is placed into its proper orbit. Placement of a satellite into a useless orbit is considered a launch loss.

Post-separation (PSP) or **commissioning** coverage provides protection against losses occurring in the period immediately following launch during which a satellite is deployed and activated. The length of the of the PSP period is defined in each contract, but typically runs for six months to a year following a launch.

In-orbit (INO) coverage protects against losses during the bulk of the operational life of a satellite, following the launch and post-separation periods. The coverage period is defined in each contract and can last up to five years. INO coverage can be offered in conjunction with launch and PSP covers or it can be offered independently of the other coverages. INO coverage is also needed for many satellites that have already been launched in order to provide a continuation of coverage over the life of the satellite.

The **bus** is standard platform on which a satellite is built. The bus provides essential components commonly needed by all satellites, like the chassis on which a satellite is built and the power system needed to operate it. A satellite is the combination of a bus and a payload.

The **payload** is the custom-designed functional part of a satellite that is built onto the bus and consists of the various transponders and sensors required to provide the intended service.

A **transponder** is the combination of receiver, transmitter and frequency converter devices on a satellite.

A **constructive total loss** is the severity at which a total loss is declared. This is usually defined to be a loss of capacity of 50% but could be as much as 75%, depending on the terms of each contract.

The definition of a **partial loss** is specified in each contract and differs by contract. The definition of a partial loss is based on technical calculations of the reduction of the expected usefulness of the satellite, both in duration and in capacity. In very general terms, the magnitude of a partial loss is based on the transponder-years a satellite achieves (or can achieve) relative to the transponder-years anticipated in the satellite design. The **transponder-years** are the product of the number of functioning transponders times the years of useful life expected for the satellite. Partial losses of 50% or more are usually deemed constructive total losses and require the maximum payment allowed by the contract.

If a policy can be placed only at a rate considered inadequate, a company may still accept a **"watching" line** on the policy. **"Watching" lines** are small lines that guarantee a complete flow of information if a failure were to occur. In addition, they keep a company in the market on a greater number of policies. If a company does not accept a line on a contract, the amount of information they receive if there is a failure will be limited to what they receive through public channels, unless they can get the information from a broker, which is not always the case.

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