IN-15

# Reusable Launch Vehicle (RLV) Market Analysis Model

A new launch vehicle will fail in the commercial marketplace unless an adequate number of flights can be sold at a price sufficient to pay for operations plus recoup the initial development cost. Of course, the price must also include a reasonable return to the investors. The Reusable Launch Vehicle (RLV) Market Analysis Model estimates an annual flight rate for a given price per flight. Used in conjunction with the RLV Economic Analysis Model, a launch vehicle concept can be examined to determine business viability with regards to investor profits. For the government, the models are used to examine the effects of incentives on RLV business viability and the macroeconomic benefits of reducing the cost of access to space.

The model is constructed to examine the effects of a VentureStar[1] class vehicle entering the competitive market around 2005. Performance for this vehicle is assumed to be 40,000 pounds to a 160x160 nautical mile orbit with a 15 foot diameter by 45 foot long cargo bay. Such a vehicle could conceivably launch all payloads envisioned for that time frame with the exception of Titan IV class payloads (due to volume constraints). By assuming such a large vehicle, the model eliminates the need to identify and manifest payloads based on mission specific requirements. Instead the model (simplistically perhaps) assumes that the vehicle can capture all missions within the date base, and the only discriminator is price per flight.

A basic model assumption is that the vehicle is capable of performing a wide variety of missions, from Space Station support to communications satellite launches. However, the model does not validate the realism of the estimated flight rate against the operations or vehicle concept. It is up to the economic model to purchase the required number of vehicles and facilities.

## Market Structure

Research into future payload requirements determined that the overall market for launch services is non-homogenous. That is, the market drivers vary by customer needs, and these needs drive the quantity and quality of service provided. Therefore, to facilitate development of the model, the payload market is divided into three segments. The payload requirements and market drivers for each segment are examined to determine the best modeling approach. The final products are independent models for the following three market segments: Inelastic, Non-Elastic, and Elastic.

The inelastic market is International Space Station (ISS) servicing. The market is termed inelastic because the RLV gets all of these missions, regardless of price per flight. The assumption is that a VentureStar class vehicle can perform all logistics flights necessary for the ISS, including crew rotations.

Launch services for communications satellites and United States Government (USG) payloads comprise the non-elastic market. The term "non-elastic" is used to describe this market because the behavior is not driven by price per flight. Rather, it is

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[1] VentureStar is the single stage to orbit, fully reusable launch vehicle concept being developed by Lockheed Martin as part of the X-33 Cooperative Agreement.

driven by the demand for communications services and USG payload budgets. As a new competitor in this market, the best RLV can do is take flights away from competing launch systems that will exist in the 2005 and beyond timeframe. The model performs a market capture analysis to determine the flight rate.

The elastic market consists of new business opportunities enabled by a drastic reduction in the price per flight. Characteristics of this market are speculative demand and high sensitivity to price changes. There is no existing or foreseen competition in this market, so the RLV captures all flights.

## The Inelastic Market

The ISS servicing market is inelastic because changes in the price per flight have no effect on the flight rate. However, to access this market, it is assumed that the RLV cost to NASA is less on an annual basis than the cost of the Space Shuttle. NASA must also make a commitment to fly on the RLV rather than the shuttle (not fly both simultaneously). The model assumes both a cost below the shuttle and a NASA commitment, giving the vehicle all ISS servicing flights, without regard for the price per flight.[2] While it may seem unrealistic to "give" these flights to the vehicle, in actuality the Agency could not commit to an RLV for ISS servicing without assurances of cost savings from eliminating shuttle operations, and it is unlikely that a company would commit to developing a vehicle the size of VentureStar without a guaranteed market.

The number of flights required to perform ISS servicing is open to debate. Planners must balance adequate ISS resupply with the desire to minimize the number of dockings in order to maximize amount of undisturbed time for microgravity experiment operation. Estimates from industry and within NASA have ranged from 10 to 16 per year. For the purposes of this model, 13 flights per year is assumed to be a realistic estimate.

A ramp-up assumption is built into the inelastic market model. The model assumes it will take three years to reach the 13 flight per year steady state ISS servicing rate. In the first year, 3 ISS missions are flow. The second year has 7 flights. Thirteen flights per year are attained in the third year of ISS support.

## The Non-Elastic Market

The market for launching commercial communication and USG payloads is driven by the demand for communications services and government payload budgets. Launch competitors vie for market share based on capability, availability, and price. To simplify

[2] Government procurement rules may inhibit an RLV company from charging a price in excess of the commercial market price. However, there are several reasons why ISS servicing missions may be more costly: (1) additional wear and tear on the vehicle due to longer stays on orbit; (2) lost revenue, also due to time spent in-space; (3) higher operations cost for longer missions; (4) greater mission complexity due to rendezvous and docking; and (5) additional costs associated with supporting a human rated module for ISS crew rotations. Also, the USG may believe that it is in the national interest to pay a premium for ISS servicing flights as a means of ensuring operator profitability while driving down the price per flight for other market segments.

this market for modeling purposes, vehicle capabilities and prices are averaged and assumptions are made about overall market behavior.

To estimate the annual number of launches for this market, data is taken from a variety of sources. Commercial geosynchronous (GEO) communication satellite launch demand is from the May 1998 "Commercial Spacecraft Mission Model Update" performed by the Commercial Space Transportation Advisory Committee (COMSTAC). The demand for low earth orbit (LEO) commercial satellite launches is taken from the "1998 LEO Commercial Market Projections" published by the Federal Aviation Administration (FAA) Associate Administrator for Commercial Space Transportation. Department of Defense (DoD) missions projections are from the August 1997 "Future Spacelift Requirements Study (FSRS)" prepared by The Aerospace Corporation for NASA and the Air Force. The estimate for NASA ELV launches is from information provided by the Office of Space Flight, NASA Headquarters. These sources also provided the data and methodology used to categorize the vehicles and the payloads. To bound the uncertainty surrounding the estimates, ranges are used. The range for the estimated number of GEO launches is assumed to be +/- 15%. For LEO commercial, the average value is the baseline scenario, the optimistic estimates are the robust projections, and the conservative rate is the average less the difference between the optimistic and average values. The range for DoD launches is the conservative and optimistic rates given by the FSRS, with the median between the two being used for the average market model. The range on the number of NASA launches is +/- 30%. The projected launch demand for the non-elastic market segment is shown below in Exhibit 1.

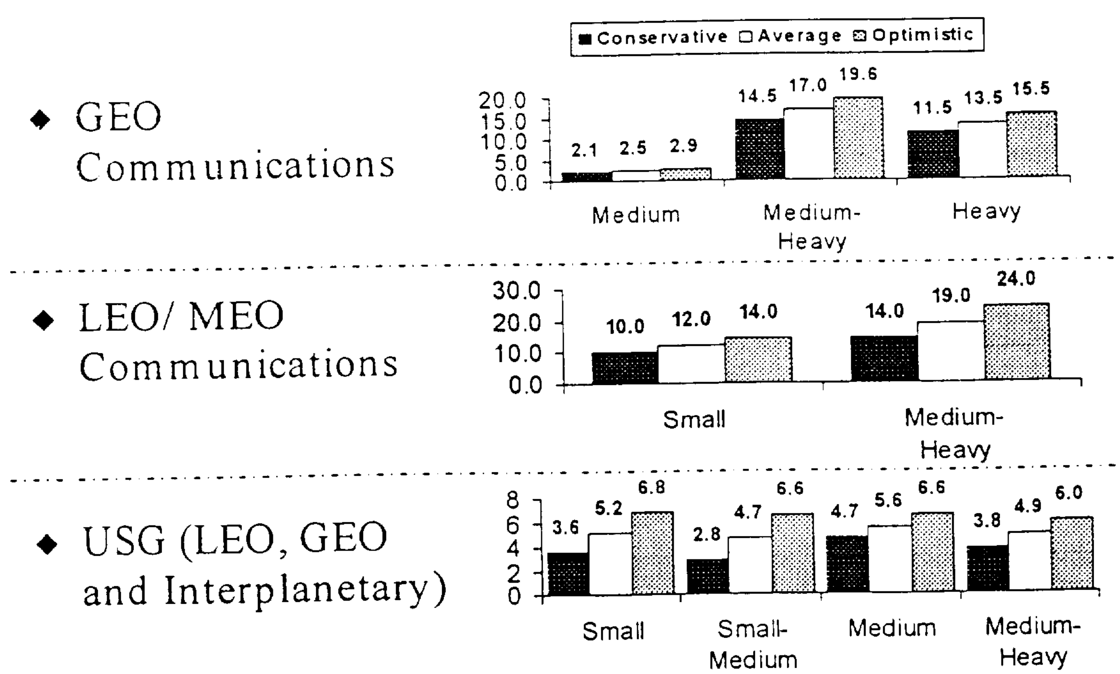


Exhibit 1. Annual Number of Non-Elastic Launches.

The competitive marketplace facing the RLV is assumed to consist of today's expendable launch vehicle (ELV) fleets plus future reusable and expendable vehicles. The source for cost and performance data for current and future competitors is the International Space Industries Report[3] (ISIR) supplemented by the International Reference Guide to Space Launch Systems, 2nd Edition published by the AIAA.

Thirteen vehicle classes encompassing both commercial and US Government (USG) payloads are used to facilitate the modeling of commercial market behavior. The market is divided into commercial and USG because satellites developed for the USG can only launch on vehicles produced within the USA. The vehicles are classed into market segments based on performance and reflect the classifications used in the COMSTAC, FAA, FSRS, and NASA Headquarters reports. For each market segment, either the lower of the average price per flight of all vehicles in a specific class or a predicted price per flight is used as the equilibrium for the market capture calculation. The predicted price per flight is based on a price per kilogram model and uses kilograms to orbit and year of first launch as the independent variables. Additional information on the price per kilogram model is available from the author. A summary of the vehicle classes and equilibrium prices are shown below in Exhibit 2.

| Vehicle Class | Price per Flight ($M) | Number of Companies | Representative Vehicles |
|---|---|---|---|
| Commercial GTO | | | |
| Medium | $36 | 4 | Delta 2, CZ-4B, M-5 |
| Medium - Heavy | $71 | 6 | Ariane 4, Atlas II, Delta 3, CZ-3A |
| Heavy | $103 | 5 | Ariane 5, CZ-3B, Proton, Zenit 3SL |
| Commercial LEO | | | |
| Small | $16 | 10 | Athena-1, Pegasus, Start, Kosmos |
| Medium - Heavy* | $64 | 10 | Ariane, Atlas, Delta, H-2A, Soyuz |
| US Government GTO | | | |
| Medium* | $45 | 1 | Delta 2 |
| Medium - Heavy* | $81 | 2 | Atlas III, Atlas HLV-A, Delta 3, Delta 4M |
| Heavy | $143 | 2 | Delta 4H, Atlas HLV |
| US Government LEO | | | |
| Small* | $12 | 3 | Athena-1, Pegasus, Conestoga |
| Small - Medium | $31 | 5 | Taurus, Delta 2, Athena -2, K-1 |
| Medium* | $53 | 2 | Atlas II, Delta 3, EELV |
| Medium - Heavy* | $68 | 2 | Atlas III, EELV |
| Heavy | $143 | 2 | EELV Heavy |

* Prices Estimated via Trend Analysis

Exhibit 2. Non-Elastic Market Classes.

The mechanism for determining RLV market share is the market capture function. This function is plotted in Exhibit 3. The market capture function estimates the change in market share based on the ratio of the RLV price per flight to the equilibrium price per flight. The function is a fifth degree polynomial fitted to exponential growth curves via regression analysis. Small deviations from the equilibrium price per flight are reflected by

[3] "International Space Industries Report," June 8, 1998, pp. 22-23.

proportionally smaller changes in market share. However, larger deviations have an increasingly greater impact, leading eventually to total market capture or total market loss. The logic behind the function is that the market is non-homogeneous in terms of price and performance. This non-homogeneity means that an RLV will face competition from other launch vehicles over a wide range of prices, not just the equilibrium price. Therefore, small deviations from the equilibrium price will have a limited impact on market share or loss. However, sufficiently large deviations will begin to either drive out competitors (by undercutting their *cost*) or make the RLV uncompetitive. These larger deviations are reflected by the exponential characteristic of the function.[4]

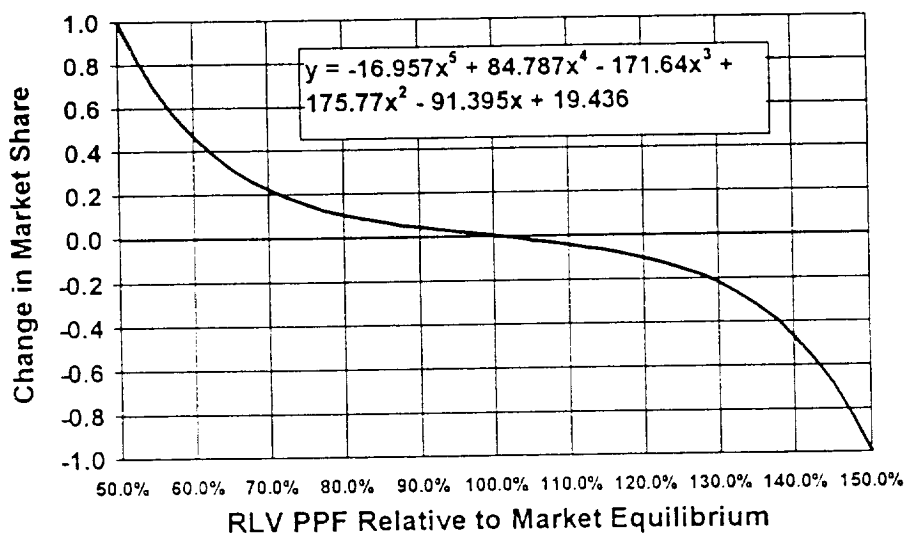


Exhibit 3. Non-Elastic Market Behavior Function.

If the RLV enters a market segment at the equilibrium price, the maximum market share that the RLV can capture is 1/N, where N is the total number of competitors in that market segment including RLV. To determine any increase or decrease in market share, the RLV price per flight is divided by the equilibrium price and the resulting value is entered into the market behavior function. The output from the function is added to the baseline (1/N) market share, then that sum is multiplied by the demand projection to obtain the annual flight rate. Exhibit 4 illustrates how the data on demand projections (Exhibit 1) and the competitive market (Exhibit 2) are combined with the market behavior function (Exhibit 3) to estimate an annual flight rate for a specific vehicle class.

[4] The original function was based on the oligopoly kinked demand curve. However, a more detailed examination of the competitive market revealed a few shortcomings in this model: some market classes have large numbers of competitors - violating a basic tenant of oligopoly; most buyers prefer to spread their risk among two or more providers - mitigating the effects of price competition; and flight rates for most (if not all) vehicles are limited by production and launch facilities. The current form of the market capture function represents an assumption of market behavior based on general economic principles, rather than a strict application of economic theory.

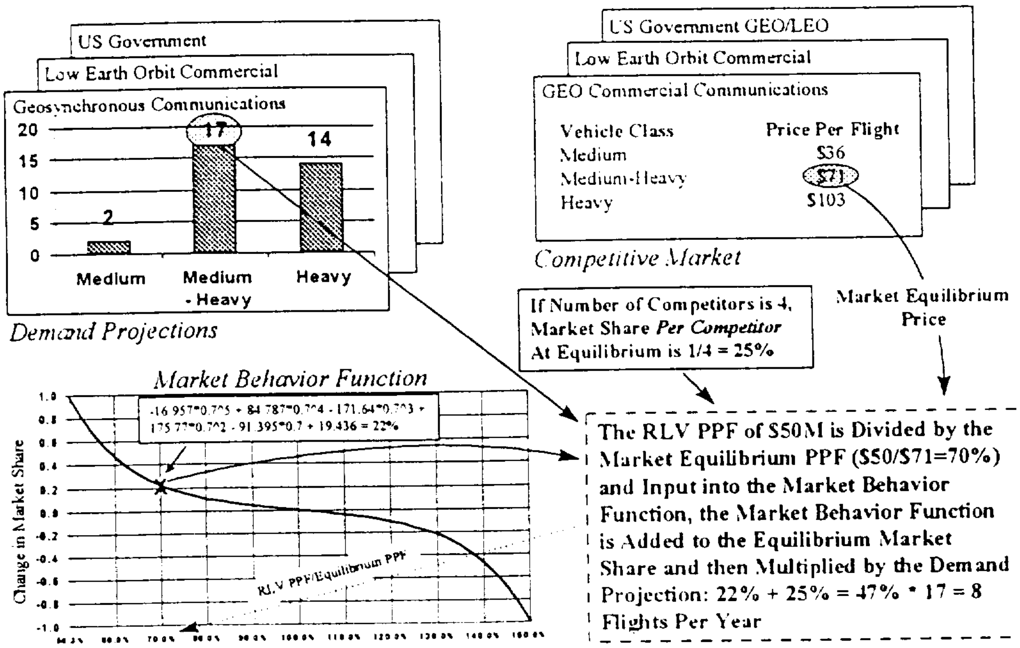


Exhibit 4. Example RLV Non-Elastic Market Share Calculation.

Two additional assumptions are incorporated into the non-elastic market analysis model. The first is the price for GEO mission upper stages. These prices are assumed to be a pass-through to the customer, but are added to the base RLV price per flight before market share calculation. The prices assumed are $10M for a Medium class payload, $20M for a Medium-Heavy, and $30M for a Heavy.

The second assumption concerns market penetration. There are several reasons why customers will take time to transition from known and understood ELV's to a new RLV. Perceived risk of a new system, existing business relationships, "teething pains" that are associated with the implementation of any complex system, and vehicle incompatibility with existing satellite designs will all work together to inhibit growth. The market penetration model assumes it will take five years to build the customer base. Initial market penetration is estimated at 20% (of capturable) and grows at a 50% rate. The second year market penetration is 30%, then 45% in year three, 68% in year four, and finally 100% in year five. Note that these values are percentages of the total market share that RLV can capture for a given price per flight[5].

## Elastic Market

In March, 1993 six aerospace companies met at Langley Research Center (LaRC) and determined "that a new, state-of-the-art launch system can provide an order of magnitude reduction in launch costs and that a reduction of that magnitude will cause the equivalent of a space industrial revolution" and "that to become economically viable, a

[5] For example, if the steady-state non-elastic market share for RLV for the Medium vehicle class is calculated to be 25%, then the market share in year four is 68% * 25% = 17%.

new launch system must generate new commercial markets." This group of aerospace companies went on to perform market exploration studies, leading to the Commercial Space Transportation Study[6] (CSTS). Data from the CSTS report is the basis for the elastic market model.

An analysis of CSTS was performed to identify new commercial markets that would develop in response to a reduction in the cost to orbit for a VentureStar class vehicle. Fourteen specific product areas were identified, which were grouped into six broad market segments: communications, manufacturing/business parks, government, tourism, entertainment, and other (including Helium-3 production and space burial). The CSTS data was converted from a dollars per pound/pounds to orbit basis to a price per flight/number of flights basis, assuming a 40K pound to LEO vehicle. Regression analysis was performed, yielding the curve shown in Exhibit 5.

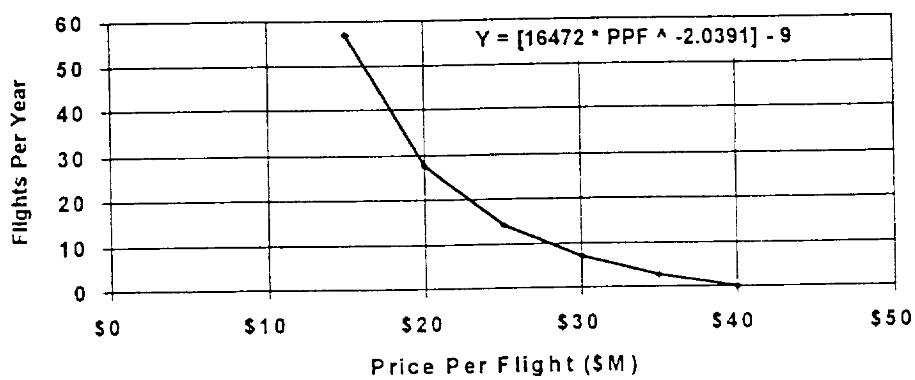


Exhibit 5. Elastic Market Behavior.

Notice that nine flights per year are subtracted from the estimate. This is an adjustment to reflect a more conservative assessment of enabling price and flight rate. After all, the data is speculative, with no hard evidence that these opportunities will arise as the price per flight falls. This adjustment has the effect of disabling the elastic market above $40M which corresponds to $1000/lb. and seems to be a reasonable cutoff point.. Also notice that this market segment is properly termed elastic, since the coefficient of elasticity is greater than one[7]. The equation in Exhibit 4 is considered an average or nominal curve. Optimistic and conservative values are calculated at +/- 50% respectively, of the average. The same market penetration approach used for the non-elastic market is used for the elastic market.

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[6] The Commercial Space Transportation Study, Final Report was published in May, 1994. The six companies participating in the study were Boeing, General Dynamics, Lockheed, Martin Marietta, McDonnell Douglas, and Rockwell. The quotes are from page 1 of the report.

[7] Watson, Donald S., Price Theory and Its Uses, Second Edition, Houghton Mifflin, Boston, 1968; p. 37. The coefficient of elasticity is the relative change in quantity divided by the relative change in price.

## Model Operation and Outputs

The model is implemented in an Excel spreadsheet and operation is straightforward. The user inputs three prices, one for each market segment. These prices are then used to generate a total flight rate estimate by market segment. A ramp-up using the market penetration assumptions previously explained is also calculated. An example set of inputs and model estimated launch rates are shown in Exhibit 6. The launch rate by market segment, for the same set of prices, is given in Exhibit 7.

***Price Inputs (FY96$M)***

| | |
|---|---|
| RLV Price Per Flight Inelastic | $75.0 |
| RLV Price Per Flight Non-Elastic | $40.0 |
| RLV Price Per Flight Elastic | $20.0 |

***Total Launch Rate Showing Ramp-Up***

| | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 |
|---|---|---|---|---|---|
| Conservative | 9.6 | 16.9 | 27.9 | 35.6 | 46.3 |
| Average | 13.1 | 22.6 | 36.3 | 48.4 | 64.9 |
| Optimistic | 17.1 | 28.2 | 44.7 | 60.9 | 83.5 |

Exhibit 6. Example Inputs and Total Launch Rate Estimate.

***Launch Rate By Market, Steady State***

| | Inelastic Market | Non-Elastic Market | | | Elastic Market | Total |
|---|---|---|---|---|---|---|
| | | GEO | LEO | USG | | |
| Conservative | 13.0 | 8.1 | 6.7 | 4.7 | 13.8 | 46.3 |
| Average | 13.0 | 9.5 | 9.1 | 5.7 | 27.6 | 64.9 |
| Optimistic | 13.0 | 10.9 | 11.5 | 6.7 | 41.4 | 83.5 |

Exhibit 7. Launch Rate by Market Segment.

An overall flight rate curve, developed assuming the same price per flight for all market segments, is shown in Exhibit 8. Analyzing the curve, several conclusions can be drawn. The first is that the only market the RLV can access at a price per fight greater than $90M is the inelastic (remember, an upper stage cost must be added to the price per flight for GEO missions). Between $40M and $90M, the non-elastic market is enabled, with flight rate increasing at a growing rate as the RLV begins to dominate more vehicle classes. Below $40M, the effects of the elastic market are clearly seen. Note that a price of $42M per flight is required to achieve a flight rate in the neighborhood of 35 per year. Analysis performed by the Engineering Cost Office indicates that flight rates in the range of 35 to 40 per year are necessary to ensure business viability of the RLV program.

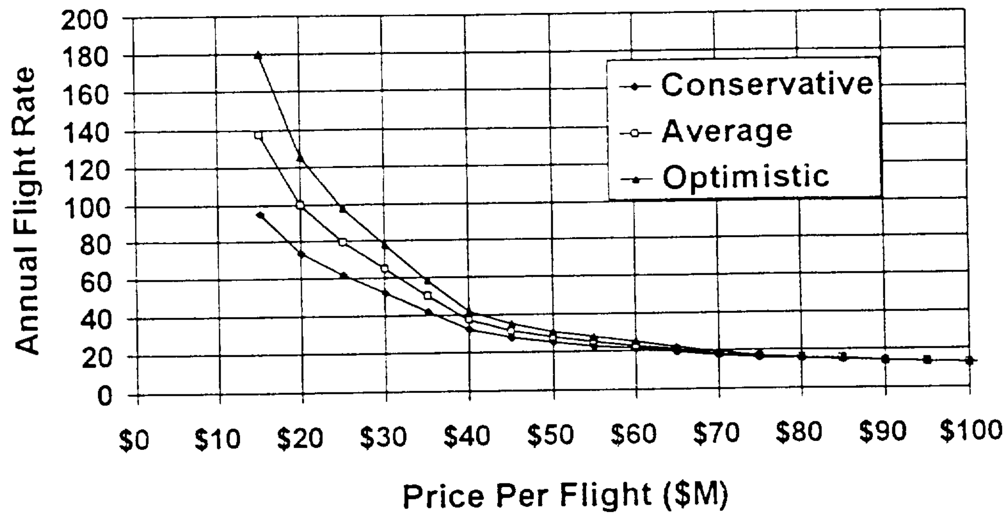


Exhibit 8. Overall RLV Flight Rate Curve.

## Sensitivity Analysis

The purpose of the sensitivity analysis is to check various assumptions for robustness. A model whose conclusions change out of proportion to changes in the quantitative assumptions may indicate the need for additional analysis. Some sensitivity has been built into the market analysis model through the use of conservative, average, and optimistic flight rates for the non-elastic and elastic markets. No range is provided for the inelastic market since the flight rate is insensitive to changes in the price per flight. However, two of the major assumptions used in the model need to be checked for robustness. These assumptions are the market capture function (Exhibit 3) and the prices for upper stages.

The market capture function is a simple approximation for what is actually a very complex and dynamic marketplace. To test the impact of the aggressiveness of the function with regards to market share increase or decrease, the model output is increased or decreased by 20% and the overall RLV flight rate is calculated. Exhibit 9 gives the results for three different price per flights. As can be seen in the graph, the model is insensitive to small changes in the aggressiveness of the market capture function. The average variation is +/- 5.5% over the price range, with a decrease in sensitivity occurring as the price per flight increases. This trend may be due to the increasing importance of the inelastic market as price per flight increases.

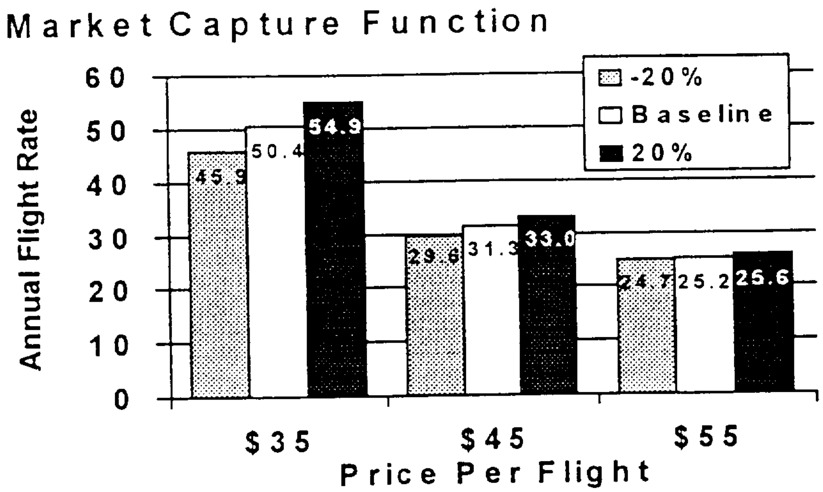


Exhibit 9. Market Capture Function Sensitivity.

The upper stage price sensitivity was examined by running the model after increasing and decreasing the prices of all upper stages by $5M. As can be seen in Exhibit 10, decreasing the price of all upper stages by $5M increased the estimated annual flight rate by 7% on average, with a greatest increase occurring at the lowest price per flight. Increasing the upper stage prices by $5M lead to an average 5% reduction in the flight rate. In order to compare the magnitude of price change with the change in flight rate, $5M is 50% of the small upper stage price, 25% of the medium upper stage, and 17% of the large upper stage.

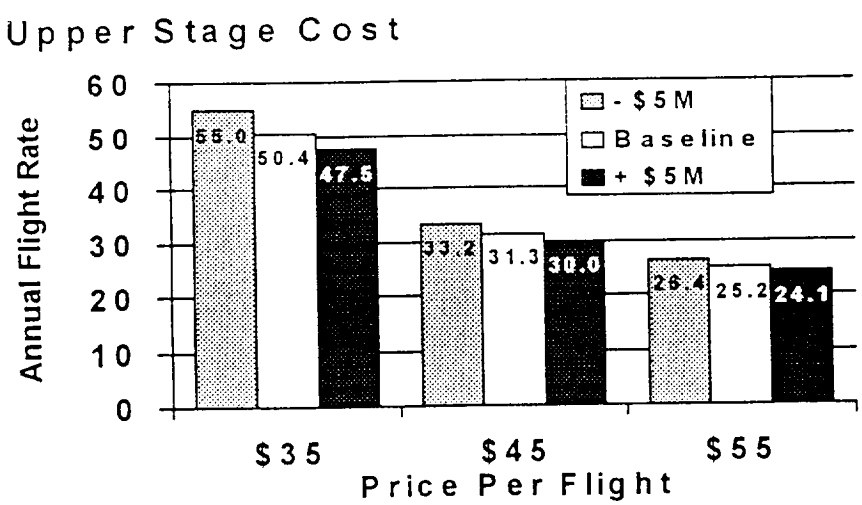


Exhibit 10. Upper Stage Price Sensitivity Analysis.

The sensitivity analysis shows that the changes in the quantitative assumptions used in the model result in minimal changes in the flight rate estimate. Therefore, the model is robust. It is important to note that this analysis has not tested the forms of the non-elastic and elastic market behavior functions. These functions are a major determinate of the annual flight rate. One way to test these functions would be to postulate alternatives and incorporate these alternatives into the model. The model would then be rerun and the estimates compared across a broad range of prices. A better approach for the elastic model would be to update the CSTS data with a thorough, professional market analysis, perhaps performed by a firm with no aerospace industry connections to insure objectivity. For the non-elastic market, development of a payload manifesting simulation model (based on compatibility, availability, and price) would allow simulations to be performed testing market response to price per flight, while incorporating the effects of other variables in the launch vehicle selection process.

**Conclusion**

The RLV Market Analysis model is at best a rough order approximation of actual market behavior. However, it does give a quick indication if the flights exists to enable an economically viable RLV, and the assumptions necessary for the vehicle to capture those flights. Additional analysis, market research, and updating with the latest information on payloads and launches would improve the model. Plans are to update the model as new information becomes available and new requirements are levied. This tool will continue to be a vital part of NASA's RLV business analysis capability for the foreseeable future.