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REGULATING REUSABLE LAUNCH VEHICLES USING RISK ANALYSIS

Roscoe M. Moore III
Georgetown University Law Center, Washington, DC

A new space launch vehicle called the Reusable Launch Vehicle (RLV) will force a change in the way that the United States regulates its commercial space launch industry. At present, the government agency responsible for licensing commercial space launches only has the authority to license the launch portion of flight. This executive agency must gain the legislative authority from Congress to regulate space vehicle reentry, because RLVs, by definition, are space launch vehicles that have both launch and reentry portions of flight. When regulatory authority is obtained from Congress, commercial launch service providers and government regulators will be forced to reevaluate the safety and financial responsibility requirements that make up commercial launch licenses. The unique technical and operational characteristics that RLVs possess over non-reusable launch vehicles will change the results of the risk based analysis that define the safety and financial responsibility requirements for licensed launch activities. Changes in the results of the risk analysis behind licensing regulations may indicate that some RLVs are too unsafe to operate or too risky to insure. Potential RLV operators should closely evaluate these changes before they approach the U.S. government for a commercial launch license.

I. Introduction

Congress has held hearings in which it has indicated that it intends to give the Department of Transportation's Associate Administrator for Commercial Space Transportation (AST or the Office) the authority to regulate and license both the launch and reentry of commercial space launch vehicles. Currently, the Office has the authority to regulate and license only the launch portion of a commercial space launch. The Expendable Launch Vehicles (ELVs) that AST currently has the authority to license are not designed to survive reentry. The Office needs the authority to license the reentry portion of flight, because it will soon have to regulate new Reusable Launch Vehicles (RLVs) that are designed to be reused many times by surviving both the launch and reentry portions of space flight.

The Office intends to provide the commercial space launch industry with standardized licensing regulations and financial responsibility requirements for commercial space launches.[1]

The regulations that govern commercial space launch licensing and financial responsibility requirements are primarily driven by a risk based analysis of the safety of a space launch vehicle. The introduction of RLVs into the commercial space launch industry will fundamentally change how commercial space launch companies and AST regulators approach the licensing and financial responsibility requirements, because the results of the risk based analysis that underlie these requirements will change as RLVs expand the bounds of traditional rocket launch operations.

The risk associated with the operation of an RLV has the potential to be much higher than the risk associated with that of an ELV, because an RLV, unlike an ELV, is designed to survive reentry and return to a particular reentry site. The reusability of RLVs will also encourage private launch companies to launch RLVs on launch azimuths and trajectories that could pose a greater financial, safety, and national security risk to the U.S. government.

The purpose of this paper is to discuss the potential change that RLVs will present to the outcome of the risk based analysis that is the foundation of the safety approval and financial responsibility requirements of a commercial launch license. By examining the potential change in the risk analysis outcome, the Federal government and the space launch industry can predict what changes will be or should be made to commercial space transportation licensing regulations in anticipation of the advent of RLVs.

II. Background

A. 1967 Outer Space Treaty and the 1972 International Liability Convention

The 1967 Outer Space Treaty [2] and the 1972 Liability Convention [3] provide a foundation for U.S. regulation of its domestic space launch industry. The United States has global responsibility for national activities conducted in outer space, whether such activities are carried out by governmental agencies like NASA and DOD or carried out by non-governmental entities like private corporations.[4] Also, a launching State is given absolute liability for damage caused to the surface of the earth or to aircraft in flight by the launch States' space objects.[5]

If a U.S. corporation launches a rocket and the United States is considered the launch state for this rocket, then the U.S. government will be absolutely liable to all persons and property potentially damaged by this rocket. A launching State is defined as (1) a State that launches or procures the launching of a space object; or (2) a State from whose territory or facility a space object is launched.[6] This means that the U.S. government is absolutely liable for damage to the surface of the earth and to aircraft caused by U.S. private corporations that procure and launch rockets in the global commercial market.

B. Commercial Space Launch Act of 1984

The Commercial Space Launch Act of 1984 established that the development of commercial launch vehicles and associated launch services by the private sector would be encouraged and supported by the U.S. government. This act also established that all private sector launches had to be authorized by a license issued by the Department of Transportation.[7]

This Act was revolutionary in 1984, because only NASA with its Space Shuttle and the Department of Defense with its ELVs were willing to launch payloads into space. Before the Act was implemented, the regulatory difficulties in obtaining the necessary approvals to conduct a commercial launch were so severe that private companies did not want to enter the market.[8] The Act provided a licensing authority to oversee launches by the commercial space launch industry and designated a government agency to regulate this new industry. This Act was codified into positive law in 1994.[9]

C. The Associate Administrator for Commercial Space Transportation

The Associate Administrator for Commercial Space Transportation (AST or The Office) under the Federal Aviation Administration (FAA) carries out the responsibilities of the Secretary of Transportation in licensing and regulating commercial space launches.[10] In April of 1988 the Office first published DOT's Commercial Space Transportation Regulations in 14 CFR Chapter III, and in June of 1988 the Office issued its first commercial space license.[11]

III. The New Regulatory Environment

The Commercial Space Launch Act only gives AST the authority to license and regulate the launch portion of a commercial space launch. A Reusable Launch Vehicle (RLV) is different from an Expendable Launch Vehicle (ELV), because an ELV is destroyed in the launch process while an RLV survives launch and reentry to be used again. Congress must amend the law written within the Commercial Space Launch Act[12] for the Office to gain the authority to regulate both launches and reentries. If the Office does not receive the additional authority to license and regulate space vehicle reentries from Congress, then the new commercial RLVs may not be licensed to fly.

Two new bills in Congress, H.R. 1702[13] and H.R. 1275[14], intend to give the Office the additional authority it needs to regulate and license re-entering space vehicles. Both bills are written to amend the Commercial Space Launch Act[15] by replacing the word "launch" with "launch or reentry" throughout the Act. Both bills also give the Office six months from the date of enactment to issue new regulations concerning licensing and financial responsibility requirements for commercial SLVs.[16]

If one of these bills is passed, the Office will receive its mandate to license and regulate reentry of RLVs, and issue financial responsibility requirements. The Office would accomplish this by eventually rewriting the NPRMs for Commercial Space Transportation Regulations and Financial Responsibility Requirements for Licensed Launch Activities.[17] In order to accommodate the arrival of RLVs, the Office will have to amend these regulations with more thought and effort than simply replacing the word "launch" with "launch or reentry". The House, in bills H.R. 1275 and H.R. 1702, intentionally provided amendments to the Commercial Space Launch Act that were broad, because Congress desires to give the Office the flexibility to use its own experience and expertise in writing new regulations for RLVs.

IV. Conditions of a Launch License

A. Aggregate Requirements for a Launch License

The Office has limited experience regulating and licensing RLVs.[18] As the Office gains experience with RLV operations over the next few years, it will be able to refine its licensing regulations, but at this moment, the Office will be forced to adapt licensing regulations that have been written for ELVs.[19]

B. Safety Review

The Office establishes a safety review to determine whether a launch license applicant is capable of launching a launch vehicle and its payload without jeopardizing the safety of people or property.[20] The safety regulation that probably would change significantly with the advent of RLV operations is the regulation evaluating acceptable flight risk through orbital insertion.[21] Acceptable flight risk is calculated using risk based analysis. The acceptable flight risk of an RLV will potentially be significantly higher than that of an ELV, because this risk would be calculated over both launch and reentry instead of launch alone.

C. Financial Responsibility Requirements

The Office establishes that a launch services provider must meet financial responsibility requirements that are calculated by the Office.[22] The Office provides space launch companies with two maximum probable loss (MPL) determinations which provide the amount of third party liability and government property insurance that the launch provider must purchase. These MPLs are calculated using a risk based analysis.

The MPLs calculated from a risk based analysis of RLV operations could be different than the MPLs calculated for ELV operations because of the technological and operational uniqueness of RLVs.[23] This may force RLV operators to pay insurance premiums that were not anticipated in their original business plans or operational budgets.

V. Risk Based Analysis of RLV Operations

A. Changes in the Results of the Risk Based Calculation Must be Advertised

This paper previously discerned in section IV that the conditions for obtaining a launch license that may change significantly for RLV operators are the conditions for financial responsibility and safety. Specifically, the risk based analysis that underlies the acceptable flight risk calculation in the safety review and the maximum probable loss calculation in the financial responsibility requirements could produce results for an RLV that are higher than the results calculated for a comparable performance ELV.[24,25] If one could estimate the calculated risk involved in operating an RLV, then AST regulators and potential RLV operators could anticipate and alleviate potential obstacles to commercial RLV flight before they arise.

B. Calculating the Launch Portion of RLV Safety Risk

(1) Total Casualty Expectation

The acceptable flight risk of a commercial launch vehicle is calculated through orbital insertion.[26] In order to obtain safety approval, the risk level associated with an applicant's launch proposal can not exceed a collective risk of 30 casualties in one million launches ($E_{total} <= 30 \times 10^{-6}$). The quantity E_{total} is the total casualty expectation, and it corresponds to the expected mean number of casualties or injuries that would occur if an ELV is launched according to a specific mission plan.[27] The quantity E is defined as the casualty expectation, which is the mean number of casualties over a subset area, A.

In general E is obtained by considering the following quantities :

1) a subset of an area, A, over which possible debris impact could occur;
2) the fragment impact probability, P, on A produced by a given launch vehicle failure;
3) the effective hazard area, H, for an impacting piece of debris within A; and
4) the number of people, N, within A that are at risk from debris impacts.[28]

These quantities are then used in the equation $E = (P*H*N)/A$ to determine what the estimated casualty is for a subset of the area over which the rocket is launched. The total casualty expectation, E_{total}, is then determined by summing up all the E's from all the subset areas the launch vehicle could affect.

If total casualty expectation, E_{total}, were calculated for the launch portion of an RLV flight, the results would probably be different than the results of a similar calculation for an ELV. The technical and operational uniqueness of an RLV would result in different inputs being placed into the casualty expectation equation of E = (P*H*N)/A, which would result in a different output for E. In addition to this, the number of subset areas over which E_{total} is calculated would increase, affecting the output of the total casualty expectation (E_{total}).[29] A discussion of what unique operational and technical characteristics of RLVs will affect the inputs to the acceptable flight risk calculations is offered below.

(2) Changes to E_{total} Caused by an RLVs Thermal Protection System

An RLV must use a thermal protection system (TPS) in order to prevent disintegration upon vehicle reentry. If an RLV blows up during the launch portion of flight, the debris caused by this explosion would probably not disintegrate as easily as the debris caused by a similar ELV failure.[30] The heat of a rocket explosion and the ensuing heat of debris reentry would usually have the debris from an ELV breaking into smaller pieces as it approaches the ground. An RLV failure would most likely cause larger and more lethal pieces of debris, because the TPS would resist the heat of the rocket explosion and the TPS on the ensuing debris would help to prevent that debris from disintegrating further. The larger debris from an RLV failure would also have a higher coefficient of lift which would help this debris to "fly" and disperse further than debris from a similar ELV failure.

The effective hazard or casualty area, H, would probably increase significantly for an RLV over an ELV, because the number of debris in the RLV's fragmentation pattern would increase and each piece of debris would be of greater size and lethality. The total number of subset areas that the total casualty expectation would have to be calculated over would also probably increase, because the "flying" debris mentioned above would be able to cover a wider swath.[31] These changes to the inputs of the total casualty expectation (E_{total}) equation caused by the TPS of the RLV would greatly increase E_{total}.

(3) Changes to E_{total} Caused by Unique RLV Operations

Potential RLV operators intend to operate their launch vehicles in ways that are considered risky today. Some of these potential RLV operators intend to launch their two stage to orbit (TSTO) and single stage to orbit (SSTO) RLVs from launch sites in Nevada and New Mexico that are surrounded by land. They intend to launch their RLVs into due east and polar orbits that would take them over land and populated areas.

If RLV operators do launch their vehicles over land and populated areas then the number of people, N, within the subset areas would probably increase dramatically. The increase in the input, N, to the casualty expectation equation, E = (P*H*N)/A, would increase E which would also cause an increase to E_{total}.

(4) Conclusion of Launch Portion of RLV Safety Risk

When total casualty expectation is calculated for the launch portion of an RLV flight the inputs of hazard area (H), the number of people within a possible impact area (N), and the number of subset areas all increase. This means that E_{total}, the total casualty expectation, could greatly increase for RLVs.[32]

The only thing that could keep E_{total} from increasing would be a decrease in the probability density , P, of the launch vehicle.[33] If RLVs proved to be more reliable than ELVs, then E_{total} might not increase.[34] It is unknown if E_{total} would exceed the 30 casualties in one million launches ($E_{total} <= 30 * 10^{-6}$) proposed by the Office[35], but E_{total} will rise dramatically unless RLV operators can prove that their launch vehicles have less probability of debris causing system failures than ELVs.

C. Calculating the Reentry Portion of RLV Safety Risk

It must be remembered that the calculation of E_{total} only covers the safety risk associated with the launch portion of an RLV flight. In order for an RLV to obtain a license it must also meet safety requirements, eventually established by AST, for the reentry portion of flight.

In 1992, the Office was presented with the responsibility of licensing the launch of a commercial reentry vehicle known as the Multiple Experiment to Earth Orbit and Return (METEOR) reentry vehicle. EER Systems Corporation, the operator of the METEOR, proposed to place the METEOR into orbit and then have it perform an unguided reentry 30 days later.[36] In licensing the METEOR, the Office decided that one license would be issued covering the launch of the METEOR on the Conestoga ELV and the reentry of the METEOR

30 days after orbital insertion.[37] The launch portion of the license defined the METEOR as a payload, therefore, the safety review of the ELV launch was the standard review.[38] The safety of the reentering payload was evaluated using three risk based criteria which are displayed as follows:

1) The probability of the reentry vehicle landing outside the designated landing site could be no greater than 3 in 1000 missions ($P <= 3 \times 10^{-3}$).

2) The additional risks to the public in the immediate vicinity (within 100 miles) of the landing site could not exceed the normal background risks of 1 casualty in a million missions on an annual basis for a single mission ($P <= 1 \times 10^{-6}$).

3) The general risks to the general public beyond the 100 mile zone could not exceed the normal background risk of 1 casualty in a million on an annual basis for a single mission ($P <= 1 \times 10^{-6}$).[39]

In determining whether the METEOR met these three criteria, the Office determined that only human-induced or intentional reentries would be analyzed. The Office felt that if the METEOR did not reenter properly upon command, the relationship between the vehicle and the vehicle operator would be broken and the METEOR would be treated as any other malfunctioning payload.[40]

In applying these criteria to the METEOR, the Office determined that some of the risk calculations could be relaxed or entirely waved. The criteria that the METEOR have a probability less than 3 in one thousand of landing outside of its designated landing site was eventually waived, because the METEOR's mission was changed to allow it to land in the ocean.[41] This risk based criteria was waived for accurate landings, because there was less likelihood of injuring a person at sea if the METEOR missed its landing zone. The Office stated that all three criteria for reentering vehicles could be waived or relaxed if the reentry plan warranted such flexibility.[42]

D. Developing a Regulatory Framework for the RLV Safety Review Using Lessons of METEOR

The Office has the opportunity to use the experience and expertise gained from conducting safety reviews of ELVs and the METEOR to assist it in writing regulations that could cover the safety review of the launch and reentry of an RLV.[43] For the launch portion of flight, the Office could evaluate an RLV using the total casualty expectation calculation that it uses for ELVs. This calculation would quantify the risk associated with launch operations and determine if this risk is within the acceptable flight risk for a licensed launch ($E_{total} <= 30 \times 10^{-6}$). For the reentry portion of flight, the Office could quantify and evaluate risk using the three criteria established in the licensing of the METEOR reentry vehicle.[44]

When a potential RLV operator establishes with AST that she has met (1) the risk based criteria for the launch portion of flight and (2) the risk based criteria for the reentry portion of flight, then she can receive a license to operate the RLV. Although the RLV operator may receive one license from AST covering launch and reentry, the risk based analysis behind the launch safety review and the reentry safety review should remain separate. If this analysis were not kept separate, RLV operators would be forced to add reentry risk into their E_{total} launch risk calculations. This would force RLV operators to evaluate the launch portion of their flight under tougher standards than comparable ELV operators.[45] This is a penalty that AST is unlikely to impose on the new RLV technology.

E. Impact of Regulatory Framework on RLV Licensing and Operations

The actual construction of the safety review for RLVs may be very similar to regulations written in the past, but the results of the risk based analysis underlying the safety review will change significantly. Potential RLV operators and AST regulators must recognize that the inputs to the risk calculations will change because of the unique operational and technical characteristics of the RLVs. These changed inputs may force RLV companies to design or operate RLVs in a safer, less aggressive manner.

An RLV, unlike an ELV, is not designed to destroy itself during the launch process. This means that it is likely that RLV designers would build their vehicles with higher fault tolerances, because they plan on using their rockets repeatedly. If RLV designers make their vehicles more reliable than comparable ELVs, then they will receive corresponding benefits from any potential AST safety review. If the probability that RLVs will fail in particular launch scenarios is reduced in comparison to ELVs operated under the same launch scenarios, then the value of the total casualty expectation (E_{total}) for a given RLV launch could be reduced as well. RLV designers need to build rockets that are more reliable than ELVs.

The easiest way for RLV operators to lower the safety risk of their vehicles is to operate them in the safest manner possible. If RLV operators operate their vehicles during launch and reentry, over water and sparsely populated terrain, like ELV operators do today, then they would limit the probability of casualty from a possible failure.

VI. Risk Based Analysis of RLV Financial Responsibility

A. Risk Based Financial Responsibility Requirements

License applicants must meet third party and government property financial responsibility requirements in order to receive a launch license.[46] The third party financial responsibility requirements are designed to insure the launch participants against claims made by third parties for bodily injury or property damage that resulted from licensed launch activities. The government property financial responsibility requirements are designed to cover claims for damage to U.S. Government property during licensed launch activities.[47]

The amount of third party liability insurance required by the Office is determined by the Office's calculation of maximum probable loss (MPL). The third party liability insurance purchased by the launch provider should not exceed the lesser of 500 million dollars or the maximum liability insurance available on the world market at a reasonable cost (determined by the Office).[48] U.S. Government property insurance requirements are also determined by the Office's calculation of maximum probable loss (MPL), and these insurance requirements should not exceed 100 million dollars.[49] In what is frequently referred to as "indemnification", the U.S. Government, subject to an act of appropriation by Congress, may pay third party claims up to 1.5 billion dollars in excess of the third party liability requirements.[50]

All of these financial responsibility requirements are designed to both promote the commercial space launch industry and protect the government from liability under the terms of the 1972 Liability Convention. The minimum insurance requirements make commercial launch companies financially responsible for launch operations, while indemnification allows these same companies to operate without the fear of unlimited liability bankrupting their companies. The insurance requirements, determined by the two MPL's, are risk based, because the statute directs it.[51] The government, in the statute, intended for launch providers to purchase financial responsibility in proportion to the risk that their commercial launch operations pose to government property and third parties.

B. MPL and Threshold Probability

A maximum probable loss (MPL) for third party liability and U.S. government property insurance is calculated by the Office to determine the financial responsibility requirements of a commercial launch operator. The definition of MPL is the maximum magnitude of loss such that there is less than a threshold probability that losses will exceed the calculated amount. The threshold probability represents the probability that loss or damage will exceed the calculated MPL.[52]

The Office sets threshold probabilities on the order of 1 in 100,000 (or 10^{-5}) and 1 in 10 million (10^{-7}) in order to calculate the financial responsibility requirements of government property and third party liability losses, respectively.[53] When a launch provider obtains the required government property insurance at a level equal to the MPL, the U.S. government should have less than a 1 in 100,000 chance (the threshold probability) of having to pay for damages in excess of that MPL. When a launch provider obtains the required third party liability insurance at a level equal to the MPL, the launch participants and the U.S. government should have less than a 1 in 10 million chance (the threshold probability) of liability for damages in excess of that MPL. If the threshold probability is low, then the imposed insurance amount, the MPL, will be high. If the threshold probability is high, then commercial launch providers will pay less.

The two MPL calculations seek to determine the maximum government property or third party losses that are reasonably likely to occur from particular failure scenarios that are probable within the threshold probability. As an example for government property insurance, if the probabilities of the loss of a launch tower, a water tank, and a building accumulate to equal the threshold probability (10^{-5}), then one would add the replacement value of those buildings in aggregate to obtain the MPL. For an example of third party liability flight risk, if the probabilities of particular damage for certain flight failure modes are accumulated to equal the threshold probability (10^{-7}), then one would add the perceived liability costs of each of these probabilities to obtain the MPL.

The accumulation of probabilities to equal the threshold probability and the calculation of the MPL are complex procedures that may involve extensive computer modeling and the use of human experts. For the purposes of this paper, it is only important to remember that these calculations are risk based. If a launch vehicle is launched over New York City, the costs that are associated with each probable failure mode will be very high which will result in a high MPL. If a launch vehicle is launched over the ocean, avoiding major shipping lanes, the costs associated with probable failure modes will be low, which will result in a low MPL. The risk based analysis underlying the financial responsibility requirements is similar to that underlying the safety requirements in that a commercial launch provider will be penalized for operations that are considered risky by contemporary rocket launch standards.

C. Calculation of MPL for the Launch Portion of RLV Flight

The introduction of RLVs into the marketplace will change the results of the risk based analysis underlying the financial responsibility requirements, because RLVs are not conventional rockets. For the launch portion of flight, the introduction of RLVs may lead to higher costs for third party liability insurance and similar costs for government property insurance. The increase in obtaining third party liability insurance would be caused by the unique technical and operational characteristics that RLVs possess over ELVs.

Any technical or operational characteristic of an RLV that could adversely affect the Office's safety review of a license applicant would also increase the value of the third party MPL calculation.[54] As mentioned previously in section V B (2) of this report, the thermal protection system (TPS) of an RLV would probably generate different debris patterns than a comparable ELV. This could cause more potential casualties, and increase the potential for third party liability claims. As mentioned in section V B (3) of this report, the unique operation of some RLVs over land and populated areas could increase potential casualties. This would also increase potential third liability liabilities.

The introduction of RLVs probably will not significantly affect the MPL calculations for the launch portion of government property insurance, because RLVs and ELVs could damage equipment at government launch sites with equal proficiency. The planned operation of RLVs from commercial launch sites would also scrap most government property insurance requirements, because these requirements are primarily designed to handle the loss of government property from launch operations at a government owned launch site.

D. Calculation of MPL for the Reentry Portion of RLV Flight

In a report prepared for the Office in 1995 by Princeton Synergetics Incorporated (PSI), it was found that the current statutory requirements used to determine financial responsibility for licensed launch operations were more than adequate for use in licensed reentry operations. It was found that the calculation of MPLs and the MPL ceilings for government property and third party liability insurance requirements should remain the same. It was also found that the government payment of excess claims provision of the Commercial Space Launch Act should apply to limit the financial risk of commercial reentry operations.[55]

Initially, when RLVs first begin commercial operations, it may be prudent to set MPLs and insurance requirements for reentry that are separate from the MPLs for the launch portion of flight. The reason this should be done is because the risk based analysis used to calculate the MPL would be different for the launch and reentry portions of flight.

In order to determine the reentry insurance requirements for an RLV, the Office would calculate two MPLs that would determine the maximum government property or third party losses that are reasonably likely to occur (i.e. within the thresholds). If the probabilities of particular damage caused by certain reentry failure modes are accumulated to equal the threshold probability (10^{-5} or 10^{-7}), then one could add the perceived liability costs of each of these probabilities to obtain MPLs. Failure modes could include an RLV producing destructive impact debris and an RLV crashing outside of its designated landing zone due to a post-reentry guidance system malfunction. Uncontrolled reentries are not considered in the financial responsibility analysis just as they are not considered in the safety review. This is explained in section V C. of this report.

E. Developing a Regulatory Framework for RLV Financial Responsibility

The Office has experience in calculating MPLs for the launch portion of rocket flight. The Office will most likely support the policy recommendations of Princeton Synergetics Incorporated and use the same risk based strategy it uses with rocket launches to calculate MPLs for vehicle reentries.[56] When RLV companies approach AST to receive a projection of their financial responsibility requirements for RLV operations, AST should give these companies four MPLs. Two of the MPLs would be used to cover government property and liability insurance for launch operations, and the other two MPLs would cover government property and liability insurance for reentry operations. The risk based MPL analysis will be separated between launch and reentry, because this will allow AST regulators and RLV operators to evaluate unique launch and reentry scenarios with more flexibility.

As an example, an RLV operator may desire to conduct 20 launches that are each different, but that same operator may want each of those launches to conclude with a reentry at the same location under standardized parameters. Under this scenario, the Office could give the RLV operator the same sets of MPLs (i.e. government property and liability MPLs) for the 20 reentries, but different sets of MPLs to cover each unique launch operation. By separating the risk based MPL calculations between launch and reentry portions, the Office and RLV operators can better discern the portions of flight over which risk mitigation may need to occur. The RLV operator would be obligated to purchase insurance that covered all four MPLs in order to meet the financial responsibility requirements and receive a license. Government indemnification against possible claims in excess of the reentry MPLs should be provided as it is provided for the launch MPLs.

F. Impact of Regulatory Framework on RLV Financial Responsibility

There is a possibility that RLV insurance costs will increase over ELV insurance costs, because an RLV should receive four separate MPLs (as opposed to two MPLs for an ELV) to insure the vehicle over both the launch and reentry portions of flight. If insurance costs for RLVs are to remain comparable to contemporary insurance costs for ELVs, either the design or operation of RLVs has to be superior to that of comparable performance ELVs.

A company launching RLVs over land and then recovering those RLVs over land must understand that the cost and the number of failure scenarios used in the calculation of the aggregate MPL have increased. The only way to keep insurance costs from escalating in step with the cost and number of possible failure scenarios, is to design an RLV that is less likely to fail than a comparable ELV. If RLVs are designed with the same fault tolerances as ELVs, then RLV operators should expect to pay higher total insurance costs for the combined launch and reentry portions of flight. If RLV operators launch and recover their vehicles in ways that ELVs have avoided, they should not be suprised by aggregate MPLs that are much higher than those given to ELV operators. The keys to low RLV insurance liability are conservative ELV-like operations and vehicle designs that are more reliable than ELVs

VII. Conclusion

The unique technical and operational characteristics that RLVs possess over ELVs will change the results of the risk based analysis that define the safety and financial responsibility requirements for licensed launch activities. The laws that regulate the U.S. commercial space launch industry will not change dramatically with the advent of RLVs, but changes in the results of the risk analysis behind these regulations will change how these laws are applied to RLVs.

Realism would dictate that the U.S. government's obligation to the 1967 Outer Space Treaty and the 1972 Liability Convention will force AST to leave the risk based criteria that governs the risk based analysis of safety and financial responsibility alone. For the safety review, this means that maximum total casualty expectation for launch is likely to remain the same, and the three criteria established to evaluate the METEOR reentry will probably not be relaxed if they are applied to RLV safety.[57] For financial responsibility requirements, the threshold probabilities for government property and third party liability insurance will remain the same, and they will also be applied to a second set of MPL calculations for the reentry portion of flight.[58]

If RLV companies build RLVs that are more robust and reliable than ELVs, and operate these RLVs in the same safe manner that ELVs have been operated in the past, then they will have no problem in obtaining the licenses they need to capture the multi-billion dollar space launch market for the U.S.

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[2] 1967 Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies
[3] 1972 Convention of International Liability for Damage Caused by Space Objects
[4] 1967 Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies, Articles VI and VII
[5] 1972 Convention of International Liability for Damage Caused by Space Objects, Article II
[6] 1972 Convention of International Liability for Damage Caused by Space Objects, Article I
[7] Commercial Space Launch Act of 1984, Public Law 98-575- Oct 30, 1984, 98 STAT 3057, 49 USC app. 2604
[8] Comments from Ms. Esta Rosenberg, Attorney-Advisor, Regulations Division, Office of the Chief Counsel, Federal Aviation Administration, U.S. Department of Transportation
[9] 49 U.S.C. Subtitle IX, Commercial Space Transportation, Chapter 701
[10] There is a delegation in 14 CFR Chapter III from the Secretary of DOT to the FAA and then 14 CFR Chapter III further delegates authority from the FAA to AST.
[11] Financial Responsibility Requirements for Licensed Launch Activities, Notice of Proposed Rule Making (NPRM), Docket No. 28635; Notice No. 96-8, RIN 2120-AF98, Federal Aviation Administration, Associate Administrator for Commercial Space Transportation, Department of Transportation, at 3. [hereinafter "NPRM for Financial Responsibility Requirements for Licensed Launch Activities"]
[12] 49 U.S.C. ch. 701.
[13] H.R. 1702 is also titled the Commercial Space Launch Act of 1997.
[14] H.R. 1275 contains some of the same material covered in H.R. 1702, except H.R. 1275 is an appropriations bill and H.R. 1702 is not.
[15] 49 U.S.C. sec 701
[16] H.R. 1275 Title III section 301 (c) (1)
[17] Actually, the regulations within the NPRMs for 14 CFR ch. III will have to be modified.
[18] The Reusable Launch Vehicle is a technology that is currently in development, therefore, AST has little experience in regulating RLVs. Regulating the METEOR reentry vehicle provided AST with some experience that could be applied to RLVs. The METEOR program will be discussed later in this paper.
[19] The Office currently utilizes a case by case approach to licensing launch operations, because of the unique aspects of the various launch proposals that are submitted. When this paper refers to "adapting" licensing regulations it is really referring to adapting the regulations in the NPRMs. The NPRMs are not officially law yet, but they serve as guidelines for AST and the rocket industry as to how AST will judge a particular launch proposal. At present, the NPRM is the only tangible way for companies to guess as to how AST will evaluate certain portions of their launch proposals. This paper seeks to discuss adapting the regulations within the NPRMs, because a paper discussing the adaptation of AST's method of making a case by case evaluation of particular launch proposals would be unclear and tedious.
[20] NPRM for Commercial Space Transportation Licensing Regulations, 14 CFR ch. III part 415.31
[21] NPRM for Commercial Space Transportation Licensing Regulations, 14 CFR ch. III part 415.35
[22] 49 U.S.C. 70112 (a)
[23] The MPLs would be calculated the same way, but the inputs to the calculation would change which would probably change the end result. Also, because risk calculation of vehicle reentry must be added, it is difficult to imagine that the MPL could remain the same.
[24] The way this risk is calculated and the results of this calculation may remain the same, but the inputs to both risk based determinations will change. This change to the inputs could result in higher acceptable flight risk or maximum probable loss if something is not done by RLV operators or AST regulators.
[25] Performance here is defined as payload mass to orbit.
[26] NPRM for Commercial Space Transportation Licensing Regulations, 14 CFR ch. III part 415.35
[27] DOT, AST, Hazard Analysis of Commercial Space Transportation, January of 1988, section 9.1.4.
[28] Ibid.
[29] These E_{total} calculations only affect the launch portion of acceptable flight safety risk calculations. The reentry portion of these

calculations will be handled later in this paper in section V (C).

[30] Most rocket explosions occur during ELV launches when the flight termination system (FTS) is activated. Many RLV companies intend to build RLVs without FTS (Pioneer Rocket Plane has a man in the loop in their proposal, hence an FTS could be out of the question), because they feel the design of their RLVs will allow for non-destructive aborts. If an RLV has a FTS then its failure mode can be compared effectively to that of an ELV. If an RLV does not have a FTS, then the risk that there will be an explosion would probably decrease while the casualties from a catastrophic failure would probably increase (because you could have a near intact rocket impacting the surface).

[31] In easier to understand terms, there will be a larger and more lethal fragmentation pattern caused by an RLV explosive failure when compared to a similar ELV failure. If you filled an exploding artillery shell with paper instead of shrapnel, the paper would disintegrate upon explosion more easily and it would not wound as many soldiers as the metal shrapnel could. It may help to look at the TPS on an RLV like shrapnel in an artillery shell. This is an extremely crude comparison, but it may help.

[32] Remember that both hazard area (H) and possible impact area (N) are in the numerator of the E_{total} equation which would have E_{total} increasing dramatically for increases in H and N.

[33] The fragment impact probability, P, produced by a given launch vehicle failure can be reduced by decreasing the likelihood that a particular failure scenario will produce impacting fragments. This is not to be confused with decreasing the chance of vehicle failure itself.

[34] If an RLV were more reliable than a comparable ELV then the possible failure scenarios would decrease. One could accomplish this by building the RLV with higher fault tolerances than a comparable ELV.

[35] Proposed in the NPRM for Commercial Space Transportation Licensing Regulations, 14 CFR ch. III sec. 415.35

[36] DOT, AST, Commercial Space Transportation; Grant of Petition for Waiver of Safety Criterion for METEOR Reentry Vehicle System, Docket 50324, 1995, at 4.

[37] DOT, AST, Commercial Space Transportation; Evaluation of COMET Reentry Vehicle System, Notice, FR Doc. 92-28400, Nov. 23, 1992.

[38] Ibid.

[39] DOT, AST, Commercial Space Transportation Evaluation Criteria for Issuance of Vehicle Safety Approval for the COMET Reentry Vehicle System., FR Doc. 92-6706, March 24, 1992.

[40] DOT, AST, Commercial Space Transportation; Grant of Petition for Waiver of Safety Criterion for METEOR Reentry Vehicle System, Docket 50324, 1995.

[41] Ibid. at 8.

[42] Ibid. at 1.

[43] This is ofcourse after legislation in H.R. 1275 and H.R. 1702 is signed into law.

[44] Because the Office has not licensed RLV operations at present, it will be assumed that the E_{total} calculation to assess acceptable flight risk at launch will be evaluated separately from the three criteria that will determine reentry safety. This means that the reentry portion of risk will not be added into the E_{total} equation evaluating launch risk.

[45] Any reentry risk added to launch risk would be subtracted from the total risk allowed during launch (i.e. E_{total} would now have to be even lower than 30×10^{-6}). This could force RLV operators to reduce their launch risk.

[46] NPRM for Financial Responsibility Requirements for Licensed Launch Activities, 14 CFR ch. III sec. 440.

[47] Ibid.

[48] 49 USC 70112.

[49] Ibid.

[50] Ibid.

[51] Ibid.

[52] DOT, AST, Financial Responsibility for Reentry Vehicle Operations., May 1995, at 29.

[53] Ibid. at 29.

[54] If the chances that AST will find something that is "unsafe" increase, then the value of the MPL is likely to increase as well.

[55] DOT, AST, Financial Responsibility for Reentry Vehicle Operations., May 1995, at 35, 36.

[56] DOT, AST, Financial Responsibility for Reentry Vehicle Operations., May 1995, at 35, 36.

[57] Discussed in this report in sections V B (1) and V (C).

[58] Discussed in this report in sections VI B and D.