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Risk Analysis and the Regulation of Reusable Launch Vehicles

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RISK ANALYSIS AND THE REGULATION OF REUSABLE LAUNCH VEHICLES

ROSCOE M. MOORE, III* **

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I. INTRODUCTION

Congress 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 re-entry 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 re-entry. Because the Office will soon have to regulate new Reusable Launch Vehicles (RLVs) that are designed to be reused many times by surviving both the launch and re-entry portions of space flight, the Office needs the authority to license the re-entry portion of flight.

The Office intends to provide the commercial space launch industry with standardized licensing regulations and financial responsibility requirements for commercial space launches.¹ Regulations that govern commercial space launch licensing and financial responsibility requirements are primarily driven by a risk-based analysis of space launch vehicle safety. 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 underlies these requirements will change as RLVs expand the bounds of traditional rocket launch operations.

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

The purpose of this Comment is to discuss the potential impact that RLVs will have on the risk-based analysis that is the foundation for the safety 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, or should, be made to commercial space transportation licensing regulations in anticipation of the advent of RLVs.

The federal government regulates commercial space launches to protect the safety of its citizens, uphold its obligations to ensure national security, and promote a thriving commercial space industry. Instead of examining the language of these regulations, this Comment will investigate the intent behind the regu-

¹ See Commercial Space Transportation Licensing Regulations, 62 Fed. Reg. 13,216, 13,217 (1997) (to be codified at 14 C.F.R. pts. 401, 411, 413, 415 and 417) (proposed Mar. 19, 1997) [hereinafter Licensing Regulations].

lations that could apply to RLVs. This intent will be investigated through a risk-based analysis of the safety restrictions and financial responsibilities associated with licensed commercial RLV operations.

II. BACKGROUND

A. OUTER SPACE TREATY AND THE INTERNATIONAL LIABILITY CONVENTION

The Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies² and the Convention on the International Liability for Damage Caused by Space Objects³ provide the foundation for United States regulation of the domestic space launch industry. These treaties provide that the United States assumes global responsibility for national activities conducted in outer space, whether such activities are carried out by governmental agencies like National Aeronautical and Space Administration (NASA) and the Department of Defense (DOD) or by non-governmental entities such as private corporations.⁴ The Liability Convention states that 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 United States 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 for all damage caused 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 United States government is absolutely liable for damage to the surface of the earth and to air-

² Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies, *opened for signature* Jan. 27, 1967, 18 U.S.T. 2410, 610 U.N.T.S. 205 (entered into force Oct. 10, 1967) [hereinafter Outer Space Treaty].

³ Convention on the International Liability for Damage Caused by Space Objects, *opened for signature* Mar. 29, 1973, 24 U.S.T. 2389, 961 U.N.T.S. 187 [hereinafter Liability Convention].

⁴ See Outer Space Treaty, *supra* note 2, arts. VI and VII, 18 U.S.T. at 2415, 610 U.N.T.S. at 209.

⁵ See Liability Convention, *supra* note 3, art. II, 24 U.S.T. at 2392, 961 U.N.T.S. at 189.

⁶ See Liability Convention, *supra* note 3, art. I, 24 U.S.T. at 2392, 961 U.N.T.S. at 189.

craft caused by United States private corporations that procure and launch rockets in the global commercial market.

The Outer Space Treaty and the Liability Convention encourage the United States government to regulate its private space launch companies. If the federal government did not closely regulate the commercial space launch industry, potential accidents by this industry could subject the United States to international hostility and unlimited financial liability.

B. COMMERCIAL SPACE LAUNCH ACT OF 1984

The Commercial Space Launch Act of 1984 established United States government support for the development of commercial launch vehicles and associated launch services by the private sector.⁷ This act also established that private sector launches had to be authorized by a license issued by the Department of Transportation (DOT).⁸

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 payloads⁹ into space. Before the Act, regulatory difficulties in obtaining the necessary approvals to conduct a commercial launch were so severe that private companies did not want to enter the satellite launch services market.¹⁰ The Commercial Space Launch Act provided a licensing authority to oversee launches by the commercial space launch industry and designated a government agency to regulate this new industry.

C. THE ASSOCIATE ADMINISTRATOR FOR COMMERCIAL SPACE TRANSPORTATION

The AST, within the Federal Aviation Administration (FAA), carries out the responsibilities of the Secretary of Transportation in licensing and regulating commercial space launches.¹¹ In April of 1988, AST first published DOT's Commercial Space

⁷ See Commercial Space Launch Act of 1984, Pub. L. No. 98-575, 98 Stat. 3055, (1984) (codified as amended at 49 U.S.C. §§ 70101-301 (1994)) [hereinafter the Commercial Space Launch Act].

⁸ See *id.* at 98 Stat. 3057-58.

⁹ A payload is an object launched into space by a launch vehicle that includes subcomponents specifically adapted to that object. See 14 C.F.R. § 401.5.

¹⁰ See Interview with Ms. Esta Rosenberg, Attorney-Advisor, Regulations Division, Office of the Chief Counsel, Federal Aviation Administration (Sept. 1997).

¹¹ There is a delegation in 14 C.F.R. Chapter III from the Secretary of DOT to the FAA and then 14 C.F.R. Chapter III further delegates authority from the FAA to AST.

Transportation Regulations,¹² and in June of 1988 AST issued its first commercial space license.¹³

III. THE NEW REGULATORY ENVIRONMENT

A. INTRODUCTION TO SPACE LAUNCH VEHICLES

The world entered the Space Age in 1957 when The Soviet Union launched and orbited the first man-made satellite, Sputnik, on top of a space launch vehicle (SLV) that was a modified intercontinental range ballistic missile (ICBM). Over the last four decades, the former Soviet Union, the United States, and other nations have achieved space flight primarily by relying on technology adapted from military ICBMs.

Military ICBMs were designed during the Cold War to deliver a nuclear payload to a distant target. An ICBM is only intended to be used once; hence, expendability was emphasized to improve efficiency. Space launch technology was developed from the ICBM because the cost of developing SLVs otherwise could have easily cost billions of dollars. All SLVs, except for the United States and Soviet Space Shuttles, have been developed from the extensive technology base provided by ICBMs.

The ELV is the only type of SLV used in the global and U.S. commercial space launch industries. The ELV is a direct descendant of the military ICBM, and it is designed to be used for only one flight. One of the reasons why space flight is so expensive is because of the one flight design philosophy of ELVs.

An ELV, similar to an ICBM, will typically achieve orbit by separating into stages. Stage separation is used to make a rocket lighter as it increases in altitude and velocity by separating large portions of that rocket. The separated stages of the rocket fall back to the earth when they are no longer needed to achieve orbit. Most ELVs are launched over water or sparsely populated terrain because their self-terminating design and separating stages make them dangerous to people and property below their flight path.

¹² See 14 C.F.R. pt. 400 (1998).

¹³ See Financial Responsibility Requirements for Licensed Launch Activities, 61 Fed. Reg. 38,992-93 (1996) (to be codified at 14 C.F.R. pt. 440) (proposed July 25, 1996). [hereinafter Financial Responsibility Requirements for Licensed Launch Activities].

B. THE REUSABLE LAUNCH VEHICLE

A Reusable Launch Vehicle (RLV) is different from an ELV, because an ELV is destroyed in the launch process while a RLV survives launch and re-entry to be used again. A RLV provides tremendous cost benefits over a comparable ELV, because a RLV can, with repeated use, recover the huge sunk costs involved in building the launch vehicle. If RLVs are operated repeatedly and regularly like aircraft then their operating costs will eventually be lower than those of ELVs. In order to obtain aircraft-like RLVs, operators will probably lobby the United States government for a regulatory environment that lessens the current safety and operational restrictions currently placed on ELVs and aircraft.

RLVs hold the potential to reduce space launch costs from over \$10,000 per pound to orbit to under \$1000 per pound to orbit. This reduction in launch costs would allow the United States space launch industry to dominate the global multi-billion dollar satellite launch services market. At present, the European Arianespace consortium dominates the geostationary earth orbit (GEO) portion of this market.¹⁴

Cheaper access to space through RLVs has the potential to give the space and satellite industry the same exponential growth that the microprocessor has given the personal computer and software industries. Tens of thousands of new high-paying jobs in the space industry could be created when new companies take advantage of the ability to launch payloads into orbit for millions of dollars per launch instead of tens or hundreds of millions of dollars per launch. Advances in technology that have encouraged RLV development would allow the United States to lead the economic revolution in space just as it has led the economic revolution in information technology.

The new technologies that enable the development of RLVs are lighter thermal protection systems (TPS), lighter than aluminum composite building materials, higher efficiency liquid rocket engines, and guidance and control (G&C) systems utilizing satellite navigation updates. New TPSs will allow RLVs to survive the high temperatures of re-entry that result from friction between the atmosphere and the rocket body. Lighter composite building materials will yield lighter weight cryogenic

¹⁴ Most companies developing RLVs desire to capture the low earth orbit (LEO) launch market. Lockheed Martin, with its Venture Star RLV design, intends to compete with Arianespace in the heavy lift GEO launch services market.

fuel tanks and lighter rocket bodies, allowing rocket designers to reduce or eliminate the separating stages that make ELVs so complex and expensive. Higher efficiency rocket engines allow RLVs to decrease their fueled weight and increase their payload capacity. New and cheaper guidance systems based on the Global Positioning Satellite System (GPS) allow RLV designers to accurately track and steer their vehicles while the rocket is out of sight or is reentering the atmosphere.

These technologies have reached the appropriate levels of maturity in the 1990s to make the private development of RLVs possible. The RLVs developed from these technologies will present regulatory challenges to the federal government, but, as mentioned previously, the arrival of RLVs into the commercial space launch market will hold benefits to the U.S. that greatly outweigh the difficulty of adapting the present regulatory environment.

C. STATUS OF REGULATION FOR REUSABLE LAUNCH VEHICLES

AST currently has the authority to license and regulate the launch portion of a commercial space launch. The Office must wait for the authority to regulate or license orbiting objects or de-orbiting re-entry vehicles.¹⁵ Congress must amend the appropriate sections within the Commercial Space Launch Act¹⁶ for the Office to gain the authority to regulate both launches and re-entries. If the Office does not receive additional authority to license and regulate space vehicle re-entries, then the new commercial RLVs may not be licensed to fly.

Two new bills in Congress, H.R. 1702¹⁷ and H.R. 1275,¹⁸ 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 Act¹⁹ by replacing the word "launch" with "launch or re-entry" throughout the Act. Both bills also give the Office six months from the date of enact-

¹⁵ The Office is part of the executive branch of government, which means that it can not make any changes to the law as established in the Commercial Space Transportation Licensing Regulations. Only the legislative branch of government can enact or amend laws. Therefore, it is up to Congress to expand AST's mandate.

¹⁶ See 49 U.S.C. §§ 70101-19 (1994).

¹⁷ Commercial Space Launch Act of 1997, H.R. 1702, 105th Cong.

¹⁸ H.R. 1275, 105th Cong. (1997) (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).

¹⁹ See 49 U.S.C. §§ 70101-19 (1994).

ment to issue new regulations concerning licensing and financial responsibility requirements for commercial SLVs.²⁰

If one of these bills is passed, the Office will receive its mandate to license and regulate re-entry of RLVs, and issue financial responsibility requirements. The Office would accomplish this by eventually rewriting the Notices of Proposed Rule Making for Commercial Space Transportation Regulations and Financial Responsibility Requirements for Licensed Launch Activities.²¹ 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 re-entry."

IV. CONDITIONS OF A LAUNCH LICENSE

A. AGGREGATE REQUIREMENTS FOR A LAUNCH LICENSE

The Office has limited experience regulating and licensing RLVs.²² As the Office gains experience with RLV operations over the next few years, it will be able to refine its licensing regulations that have been written for ELVs.²³

In order to obtain a commercial launch license from the Office, a United States launch provider must satisfy launch license and financial responsibility requirements.²⁴ A launch provider

²⁰ See H.R. 1275, 105th Cong. § 301(c)(1) (1997).

²¹ Actually, the regulations within 14 C.F.R. ch. III will have to be modified.

²² Reusable Launch Vehicles are currently being developed, so AST has little experience in regulating RLVs. Regulating the METEOR re-entry vehicle (which will be discussed later) provided AST with some experience that could be applied to RLVs.

²³ The Office currently utilizes a case-by-case approach to licensing launch operations because of the unique aspects of the various launch proposals submitted. "Adapting" licensing regulations refers to adapting the regulations in the Notices of Proposed Rule Making (NPRM). The NPRMs are not official law, but serve as guidelines for AST and the rocket industry as to how AST will judge a particular launch proposal. Currently, the NPRM is the only basis for companies to estimate how AST will evaluate certain portions of their launch proposals. This Article seeks to discuss adapting the regulations within the NPRMs because a paper discussing the adaptation of AST's methods of making a case-by-case evaluation of particular launch proposals would be unclear and tedious.

²⁴ These requirements are respectively described in the NPRM for Commercial Space Transportation Licensing Regulations, 14 C.F.R. § 415, and the NPRM for Financial Responsibility Requirements for Licensed Launch Activities, 14 C.F.R. § 440. The NPRMs are not law until they officially replace the regulations in 14 C.F.R. ch. III, but serve as guidelines for what AST intends to do. One can almost view the updated regulations within a NPRM as law because AST has already received the authority from Congress to make these changes to the law. The NPRM is just a way for AST to involve industry and the public in designing the

with a RLV will have to pass a policy review, a payload review, a safety review, and financial responsibility requirements espoused for ELVs in order to meet the conditions for a launch license.

B. POLICY REVIEW

The Office establishes a policy review for the license application which addresses issues that may affect United States national security or foreign policy interests.²⁵ The policy review focuses on the proposed mission including foreign ownership, technology transfer, and other issues that are handled primarily by other federal agencies like the Department of State and the Department of Defense. Although many of the issues addressed in the policy review are of concern to potential RLV operators, the policy review should not present operators with RLV specific problems.

The results of a policy review should be the same whether a launch operator uses a RLV or an ELV. The unique technological and operational characteristics of RLVs would not jeopardize United States national security, foreign policy, or international obligation interests to a greater than ELVs do. Possible scenarios in which a RLV could jeopardize national security, foreign policy, or international obligations apply to ELVs as well.²⁶ The present regulations describing the policy review may eventually be rewritten, but they will not be rewritten to specifically address the regulatory challenges caused by the new technology found in RLVs.²⁷

most efficient regulations to implement laws and policies that Congress has already evoked. This Comment will assume that the NPRMs obtained from AST's world wide web site in July of 1997 represent what AST wants the commercial space launch industry to follow in July of 1997.

²⁵ See 14 C.F.R. § 415.23

²⁶ As an example, Kistler Aerospace Corporation wants to launch its K-1 RLV from Australia. This is not a problem for the policy review that is unique to RLVs, because a U.S. company could request to launch an ELV from Australia. If Kistler wanted to launch from Australia and land in the U.S., problems for the policy review may result due to the unique characteristics of a RLV. Such scenarios, though, are better discussed in an academic paper that desires to stretch the limits of the possible legal ramifications of RLV operation. This Comment will not address this topic.

Military application of RLVs will present problems in the future for U.S. obligations under international treaties. Military uses of RLVs will not be addressed herein as this Comment focuses on commercial uses of RLVs.

²⁷ The Office handles situations not addressed in the regulations in the NPRMs on a case-by-case basis.

C. PAYLOAD REVIEW

The Office uses a payload review to determine if the license applicant or payload operator has obtained all the required licenses, authorizations, and permits needed to carry a payload into space.²⁸ The payload review is designed to ensure that the launch services provider has registered the payload with the appropriate federal agency and to ensure that the payload is safe enough to be launched into space.

Nothing in the payload review would have to be changed specifically for RLV operations. Any payload that could be flown in the future on a RLV could also be flown at present on an ELV. The present regulations describing the payload review may eventually be rewritten, but they will not need to be rewritten specifically to address the regulatory challenges resulting from the new technology found in RLVs.

D. SAFETY REVIEW

The Office uses a safety review to determine whether a launch license applicant is capable of launching a vehicle and its payload without jeopardizing the safety of people or property.²⁹ Most of the safety review regulations could be used to review the safety of a RLV as adequately as they review the safety of an ELV. Regulations calling for safety organization, launch safety design and operation, a communications plan, and an accident investigation plan would not have to change significantly for RLV operations.³⁰ Substituting the words "launch or re-entry" for "launch" in the aforementioned regulations, these would most likely make adequate the regulations for RLV operations.

The only safety regulation that would probably change significantly with the advent of RLV operations is the regulation evaluating acceptable flight risk through orbital insertion.³¹ Acceptable flight risk is calculated using a risk-based analysis. The acceptable flight risk of a RLV could be significantly higher than that of an ELV because risk calculation would include both launch and re-entry instead of launch alone. The unique technological and operational characteristics of a RLV, as compared to that of an ELV, will change the results of the acceptable flight risk calculations. This change will result in RLV operators and

²⁸ See Licensing Regulations, *supra* note 1.

²⁹ See *id.* at 13,242.

³⁰ See *id.* at 13,242-43.

³¹ See *id.* at 13,242.

AST regulators reevaluating how they balance risk with performance in rocket vehicle design, operation, and regulation.

E. FINANCIAL RESPONSIBILITY REQUIREMENTS

A launch services provider must meet financial responsibility requirements that are calculated by the Office.³² 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 maintain.³³ 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.³⁴ This may force RLV operators to maintain insurance that was not anticipated in their original business plans or operational budgets. The potential change in the results of the risk-based analysis used to calculate the MPL may change the way that RLV operators and AST regulators view the impact of the financial responsibility regulations.

V. RISK-BASED ANALYSIS OF RLV OPERATIONS

A. CHANGES IN THE RESULTS OF THE RISK-BASED CALCULATION MUST BE ADVERTISED

This Article 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 higher results for a RLV than those calculated for a comparable ELV performance.³⁵ If one could estimate the risk involved in operating a

³² See 49 U.S.C. § 70112(a) (1994).

³³ See 49 U.S.C. § 70112(a)(3) (1994).

³⁴ 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 re-entry must be added, it is difficult to imagine that the MPL could remain the same.

³⁵ 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.

RLV, then AST regulators and potential RLV operators could anticipate and alleviate potential obstacles to commercial RLV flight before they arise.

Arguably, the two most important questions that commercial launch license applicants ask the Office and themselves are if the operation of their particular launch vehicle is safe and what level of liability insurance they will have to maintain. If a commercial launch is not considered to be safe or insurable, then the regulations that are associated with launch safety and insurability should warn potential launch applicants of this situation. In order for this to happen, any change in the results of the risk-based analysis underlying both launch vehicle safety and financial responsibility must be advertised and addressed. Potential RLV operators need to know, before they apply for a launch license, that a RLV's unique technical and operational characteristics compared to an ELV will change the inputs and results of these risk-based calculations.

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.³⁶ In order to obtain safety approval, the risk level associated with an applicant's launch proposal can not exceed a collective risk of thirty casualties in one million launches ($E_{total} \leq 30 \times 10^6$).³⁷ 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.³⁸ 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

Performance here is defined as payload mass to orbit.

³⁶ See Licensing Regulations, *supra* note 1, at 13,242.

³⁷ See *id.*

³⁸ See *id.* at 13,320.

4) the number of people, N , within A that are at risk from debris impacts.³⁹

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 determined by summing the E 's from all the subset areas the launch vehicle could affect.⁴⁰

If total casualty expectation, E_{total} , were calculated for the launch portion of a 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 E . In addition, the number of subset areas over which E_{total} is calculated would increase, affecting the output of the total casualty expectation.⁴¹ A discussion of unique operational and technical characteristics of RLVs affecting the inputs to the acceptable flight risk calculations follows.

2. Changes to E_{total} Caused by a RLV's Thermal Protection System

It was discussed previously in Section III that a RLV must use a thermal protection system (TPS) in order to prevent disintegration upon vehicle re-entry. If a 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.⁴² The heat of a rocket explosion and the ensuing heat of debris re-entry would usually cause the debris from an ELV to break into smaller pieces as it approaches the ground. A RLV failure would most likely cause larger and more

³⁹ See Federal Aviation Administration, Office of the Associate Administrator for Commercial Space Transportation, *Hazard Analysis of Commercial Space Transportation* 9-8 to 9-9 (visited Oct. 26, 1998) <<http://ast.faa.gov/reports>>.

⁴⁰ See *id.* at 9-9.

⁴¹ These E_{total} calculations only affect the launch portion of acceptable flight safety risk calculations. The re-entry portion of these calculations will be handled later in this paper. See *infra* Part IV.B.3.

⁴² Most rocket explosions during ELV launches occur 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 a RLV has a FTS then its failure mode can be compared effectively to that of an ELV. If a 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).

lethal pieces of debris because the TPS would resist the heat of the rocket explosion and further disintegration. The larger debris from a RLV failure would also have a higher coefficient of lift which would help this debris to "fly" and disperse over a broader area than debris from a similar ELV failure.

The effective hazard or casualty area, H , would probably increase significantly for a RLV compared to an ELV because the number of debris particles 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.⁴³ These changes to the inputs of the total casualty expectation 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. For RLV companies like Kistler Aerospace Corporation, which intend to design and operate TSTO RLVs, launching over land may be the only option because recovery of the reusable first stage would be difficult if it were launched over the ocean.⁴⁴

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}).

⁴³ In easier to understand terms, there will be a larger and more lethal fragmentation pattern caused by a RLV explosive failure 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. It may help to look at the TPS on a RLV like shrapnel in an artillery shell. This is an extremely crude comparison, but it may help.

⁴⁴ Kistler Aerospace Corporation intends to fly their first stage back to the launch area, but this can be a difficult task for a ballistic vehicle with limited lift and cross range capability.

4. Conclusion of Launch Portion of RLV Safety Risk

When total casualty expectation is calculated for the launch portion of a 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.⁴⁵

The only thing that could keep E_{total} from increasing would be a decrease in the probability density, P , of the launch vehicle.⁴⁶ If RLVs proved to be more reliable than ELVs, then E_{total} might not increase.⁴⁷ It is unknown if E_{total} would exceed the thirty casualties in one million launches ($E_{total} < = 30 * 10^6$) proposed by the Office,⁴⁸ 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 RE-ENTRY PORTION OF RLV SAFETY RISK

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

1. The METEOR Re-entry Vehicle System

In 1992 the Office was presented with the responsibility of licensing the launch of a commercial re-entry vehicle known as the Multiple Experiment to Earth Orbit and Return (METEOR) re-entry vehicle.⁴⁹ EER Systems Corporation, the operator of the METEOR, proposed to place the METEOR into orbit and have it perform an unguided re-entry thirty days later.⁵⁰ In licensing the METEOR, the Office decided that one license would be issued covering the launch of the METEOR on the

⁴⁵ Remember that both hazard area (H) and possible impact area (N) are in the numerator of the E_{total} equation so E_{total} will increase dramatically with increases in H and N .

⁴⁶ 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 should not be confused with decreasing the chance of vehicle failure itself.

⁴⁷ If a RLV was 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.

⁴⁸ See Licensing Regulations, *supra* note 1, at 13,242.

⁴⁹ See *id.* Grant of Petition for Waiver of Safety Criterion for METEOR Reentry Vehicle System, 60 Fed. Reg. 39,476 (1995).

⁵⁰ See *id.*

Conestoga ELV and the re-entry of the METEOR thirty days after orbital insertion.⁵¹ The launch portion of the license defined the METEOR as a payload, therefore, the safety review of the ELV launch was the standard review.⁵² The safety of the reentering payload was evaluated using three risk-based criteria which are displayed as follows:

- 1) The probability of the re-entry vehicle landing outside the designated landing site could be no greater than 3 in 1000 missions ($P \leq 3 \times 10^{-3}$);
- 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 ($P \leq 1 \times 10^{-6}$);
- 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 ($P \leq 1 \times 10^{-6}$).⁵³

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.⁵⁴

In applying these criteria to the METEOR, the Office determined that some of the risk calculations could be relaxed or entirely waived. The criteria that the METEOR have a probability less than three 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.⁵⁵ 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.⁵⁶ The Office stated

⁵¹ See Commercial Space Transportation; Evaluation of COMET Reentry Vehicle System, 57 Fed. Reg. 55,021 (1992).

⁵² See *id.*

⁵³ See Commercial Space Transportation Evaluation Criteria for Issuance of Vehicle Safety Approval for the COMET Reentry Vehicle System, 57 Fed. Reg. 10,213, 10,215 (1992).

⁵⁴ See Commercial Space Transportation; Grant of Petition for Waiver of Safety Criterion for METEOR Reentry Vehicle System, 60 Fed. Reg. 39,476, 39,477 (1995).

⁵⁵ See *id.* at 39,478.

⁵⁶ See *id.*

that all three criteria for reentering vehicles could be waived or relaxed if the re-entry plan warranted such flexibility.⁵⁷

2. *Applying METEOR Lessons to RLV Safety Review*

The approach the Office took in licensing the launch and recovery of the METEOR is a rational way for the Office to license the launch and re-entry of RLVs. The Office would probably give one license to a launch applicant that would cover both the launch and re-entry portions of flight. The Office could evaluate the launch portion of the RLV license using the safety review criteria it has developed for ELVs, and then evaluate the re-entry portion of the license using the same criteria it developed for the METEOR.

The Office could find some trouble in evaluating the re-entry of RLVs with criteria developed from the re-entry of the METEOR because the operational and technical characteristics of a RLV are different from those of the METEOR. Any potential RLV would be much larger than the METEOR, increasing the probability of harm if there were a failure. A potential RLV may also carry significant amounts of cryogenic fuel upon re-entry that would make the RLV a large fire bomb if it failed upon re-entry.⁵⁸ The TSTO RLVs like the Kistler K-1 would have two different reentering vehicles to evaluate under the risk-based criteria. Finally, RLV operators that intend to operate their RLVs inland could have potential debris impact areas that encompass large swaths of populated territory.

D. DEVELOPING A REGULATORY FRAMEWORK FOR THE RLV SAFETY REVIEW

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 governing the safety review of the launch and re-entry of a RLV.⁵⁹ For the launch portion of flight, the Office could evaluate a RLV using the total casualty expectation calculation that it uses for ELVs. This calculation would quantify the risk associated with launch operations and could be used to determine if this risk is within the

⁵⁷ See *id.* at 39,478-79.

⁵⁸ A fire bomb in the sense that the fuel would ignite and create a tremendous explosion.

⁵⁹ This is of course after legislation in H.R. 1275 and H.R. 1702 is signed into law.

acceptable range for a licensed launch ($E_{total} \leq 30 \times 10^6$). For the re-entry portion of flight, the Office could quantify and evaluate risk using the three criteria established in the licensing of the METEOR re-entry vehicle.⁶⁰

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 re-entry portion of flight, she can receive a license to operate the RLV. Although the RLV operator may receive one license from AST covering launch and re-entry, the risk-based analysis behind the launch safety review and the re-entry safety review should remain separate. If these analyses were not kept separate, RLV operators would be forced to add re-entry 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,⁶¹ 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. AST regulators and potential RLV operators must recognize that the inputs to the risk calculations will change because of the unique operational and technical characteristics of the RLVs. These different inputs will either force the Office to relax or waive some of its risk-based requirements, or it may force RLV companies to design or operate RLVs in a safer, less aggressive manner.

A 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

⁶⁰ 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 re-entry safety. This means that the re-entry portion of risk will not be added into the E_{total} equation evaluating launch risk.

⁶¹ Any re-entry 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.

ELVs, they will receive corresponding benefits from an 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 re-entry, over water and sparsely populated terrain, like ELV operators do today, then they would limit the probability of casualty from a possible failure. At present, some RLV companies like Kistler Aerospace feel obligated to launch from inland launch sites over populated regions of the U.S. or Canada.⁶² These companies may want to consider choosing traditional launch sites like Vandenberg AFB for polar orbits and Cape Canaveral for due east orbits to avoid dangerous flight over populated territories.⁶³ Companies designing ballistic RLVs like Kistler may also want to consider launching their rockets from off-shore platforms like the Boeing Sea Launch Venture. By choosing more conservative launch and recovery strategies, RLV companies could avoid having to ensure extreme reliability of their vehicles.

Some RLV concepts, like those of Pioneer Rocket Plane and Kelly Aerospace Corporation, intend to use a carrier aircraft and some form of a trans-atmospheric, winged aerospace vehicle to place a payload into orbit.⁶⁴ These concepts could mitigate risk

⁶² Kistler intends to conduct its U.S. launches from Nevada. If Kistler launches due east from Nevada, their launch path will take them over the middle of the continental U.S. If Kistler launches into polar orbits (due north), then its flight path will take it over the width of Canada.

⁶³ Vandenberg AFB and Cape Canaveral are not the only options available to these RLV companies. Commercial launch sites will soon be available in Alaska, California, Florida, New Mexico and other places throughout the United States. These options will provide flexibility when RLV companies determine what site to use when launching into polar or due east orbits.

⁶⁴ Pioneer plans to have a manned aerospace vehicle fly from a runway to a refueling tanker, take on liquid oxygen, use a rocket engine to boost the aerospace vehicle, an upper stage, and a satellite into space. Upon reaching space, the aerospace vehicle with pilot will glide back to earth for a runway landing, while the upper stage ignites and carries the satellite to low earth orbit (LEO).

In the Kelly concept, the unmanned aerospace vehicle is towed to altitude by a large aircraft, and upon release from the tow plane, the aerospace vehicle ignites its engine taking the vehicle, an upper stage, and a satellite into space. The up-

by conducting the majority of their operations over the ocean or sparsely populated terrain. If they used runways near Vandenberg AFB for polar launches and runways on the east coast for due east launches, most of their launch operation and vehicle recovery activities would be conducted over the ocean. From rocket engine ignition to orbital insertion, these RLVs would have comparable or superior safety to ELVs launched from the same areas on the same launch azimuths and trajectories.⁶⁵

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.⁶⁶ The third party financial responsibility requirements are designed to insulate the launch participants against claims made by third parties for bodily injury or property damage resulting 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.⁶⁷

The amount of third party liability insurance required by the Office is determined by the Office's calculation of maximum probable loss (MPL). 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 (as determined by the Office).⁶⁸ United States 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.⁶⁹ In what is fre-

per stage places the satellite into orbit while the aerospace vehicle glides to a runway landing.

⁶⁵ They would be safe for the same reason that the Orbital Sciences Pegasus XL vehicle is safe from rocket ignition to orbital insertion. If the Pegasus XL fails immediately after launch, it will fail at sea, while a ground launched ELV failing near the earth would cause damage to the surrounding area. AST's experience with the Pegasus XL has shown that risk mitigation for launch concepts involving trans-atmospheric vehicles is manageable.

⁶⁶ See Financial Responsibility Requirements for Licensed Launch Activities, *supra* note 13.

⁶⁷ See *id.*

⁶⁸ See 49 U.S.C. § 70112 (1994).

⁶⁹ See *id.*

quently 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 coverage payments.⁷⁰

All of these financial responsibility requirements are designed to promote the commercial space launch industry while protecting the government from liability under the terms of the 1972 Liability Convention. 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. Insurance requirements, determined by the two MPLs, are risk-based, pursuant to the statute.⁷¹ The government 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.⁷²

B. MPL AND THRESHOLD PROBABILITY

A 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.⁷³

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.⁷⁴ 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 insur-

⁷⁰ See *id.*

⁷¹ See *id.*

⁷² See *id.*

⁷³ See Department of Transportation, *Financial Responsibility for Reentry Vehicle Operations* 29 (visited Oct. 26, 1998) <<http://www.ast.faa.gov/reports>> [hereinafter *Financial Responsibility*].

⁷⁴ See *id.*

ance 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 required insurance coverage, 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 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. As 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 Article, it is only important to remember that these calculations are risk based. If a launch vehicle is launched over New York City, the costs associated with each probable failure 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 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 and gov-

ernment 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.

Technical or operational characteristics of a 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.⁷⁵ As mentioned previously in Section V.B.2. of this Article, the thermal protection system of a RLV would probably generate different debris patterns than a comparable ELV. This could potentially cause more casualties, increasing the likelihood of third party liability claims. As mentioned in Section V.B.3., the unique operation of some RLVs over land and populated areas could increase potential casualties, which would also increase potential 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 can 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 RE-ENTRY 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 re-entry operations.⁷⁶ It was also determined that the calculation of MPLs and the MPL ceilings for government property and third party liability insurance requirements should remain the same.⁷⁷ 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 re-entry operations.⁷⁸

⁷⁵ If the chances that AST will find something that is "unsafe" increase, then the value of the MPL is likely to increase as well.

⁷⁶ See *Financial Responsibility*, *supra* note 73, at 32-3.

⁷⁷ See *id.* at 34-6.

⁷⁸ See *id.* at 35-6.

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

In order to determine the re-entry insurance requirements for a 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 re-entry failure modes are accumulated to equal the threshold probability (10^{-5} or 10^{-7}), then the perceived liability costs of each of these probabilities could be added to obtain MPLs. Failure modes could include a RLV producing destructive impact debris and a RLV crashing outside of its designated landing zone due to a post-re-entry guidance system malfunction. Uncontrolled re-entries 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 Article.

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 PSI and use the same risk-based strategy it uses with rocket launches to calculate MPLs for vehicle reentries.⁷⁹ 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 re-entry operations. The risk-based MPL analysis will be separated between launch and re-entry, because this will allow AST regulators and RLV operators to evaluate unique launch and re-entry scenarios with more flexibility.

As an example, a RLV operator may desire to conduct twenty launches from different locations, but may want each of those launches to conclude with a re-entry at the same location under standardized parameters. Under this scenario, the Office could

⁷⁹ See *id.*

give the RLV operator the same sets of MPLs (i.e., government property and liability MPLs) for the twenty re-entries, but different sets of MPLs to cover each unique launch operation. By separating the risk-based MPL calculations between launch and re-entry 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 re-entry 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 a RLV should receive four separate MPLs (as opposed to two for an ELV) to insure the vehicle over both the launch and re-entry 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 costs 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 line with the costs and number of possible failure scenarios is to design a 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 re-entry portions of flight. If RLV operators launch and recover their vehicles in ways that ELVs have avoided, they should not be surprised 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

Risk analysis is the technical process for identifying, characterizing, quantifying and evaluating hazards.⁸⁰ The Office bases its

⁸⁰ *See id.*

safety review and financial responsibility requirements on a risk-based analysis because it needs an objective and technical process to evaluate the probability and consequences of undesirable events happening in licensed launch activities. This evaluation allows the Office and launch license applicants to answer the two most fundamental questions concerning the regulation of commercial space launch vehicles: (i) is the launch vehicle safe to fly, and (ii) can it be insured at a reasonable price?

The unique technical and operational characteristics of RLVs compared to ELVs will change the results of the risk-based analysis defining 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 analysis behind these regulations will change how these laws are applied to RLVs.

The risk assessment for RLVs will extend from the launch portion of flight to both the launch and re-entry portions of flight. This extension will cause an increase in the total potential risk of RLV operations. This potential increase may make RLVs unsafe to operate or too risky to insure, unless potential RLV operators take appropriate action before they approach AST for a license.

The U.S. government, through AST, desires to make its commercial launch industry as safe as possible, because it is obligated by international treaty to do so. The 1967 Outer Space Treaty makes the U.S. government responsible for all space launches conducted by U.S. private companies. The 1972 Liability Convention makes the U.S. government financially responsible for any damage that may occur from private corporation mishaps. This means that it is unlikely that the government, through AST, will relax the safety review and financial responsibility requirements for future commercial RLV operations because those requirements have evolved from international agreements.

Realism would dictate that the U.S. government's obligations under the 1967 Outer Space Treaty and the 1972 Liability Convention will force AST to leave the 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 re-entry will probably

not be relaxed if they are applied to RLV safety.⁸¹ 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 re-entry portion of flight.⁸²

It is the duty of RLV operators to build and operate RLVs that satisfy AST's future licensing requirements. Because the U.S. government is bound by the 1967 Outer Space Treaty and the 1972 Liability Convention, no amount of lobbying by potential RLV operators will relax AST's risk-based criteria. 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 United States.

⁸¹ See discussion *supra* Parts V.B.1.-C.1.

⁸² See discussion *supra* Parts VI.B., D.