INTERIM REPORT ON RLV LICENSING ISSUES

Commercial Space Transportation Advisory Committee
(COMSTAC)
RLV Working Group

February 4, 1999

REVISION PAGE

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A	Added 3.3a & Figure 5 to Space Access 2.2b & admin changes	2-8-99
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1.0 EXECUTIVE SUMMARY
(Submitted by Kelly Space & Technology)

The Commercial Space Act of 1998 granted to the FAA authority to license re-entry by launch vehicles. The Act requires the FAA to issue a Notice of Proposed Rulemaking (NPRM) addressing regulations for re-entry licensing by May 1999. In addition to the NPRM direction to the FAA, the FAA Associate Administrator for Commercial Space Transportation (AST) requested that the Commercial Space Transportation Advisory Committee (COMSTAC) provide support in two other areas.

The first area was set forth in the October 8, 1998 letter from the AST Associate Administrator. This letter identified certain public safety issues for both launch and re-entry of Reusable Launch Vehicles (RLVs) and Re-entry Vehicles (RVs).

A. Criteria for defining the types of test flight programs required to allow over-flight of populated areas by RLV's during launch and landing.
B. Criteria for transitioning from a flight test program to an operational program.
C. Human rating safety standards for RLV's in the following areas:
   1. Life support requirements
   2. Training and personnel qualifications
   3. Functional responsibility for public safety-related operations

The second area addressed a group of broader regulatory issues of interest and concern to the emerging RLV industry. Following is the current list of (11) criteria comprising the interim guidelines for RLV's.

1. Public Expected Casualty
2. Safety Process Methodology
3. Human Intervention Capability
4. Positive Human Initiation of Re-entry Activities
5. Flight Data Monitoring and Recording
6. Non-nominal Re-entry Risk Mitigation
7. Over-flight of Populated Areas
8. Re-entry/Landing Site Risks
9. Pre-planned, Pre-approved Staging Impact Points and Abort Landing Sites
10. Flight Test Demonstration Program
11. Pre-flight Inspection and Checkout

The COMSTAC RLV Working Group (WG) is providing the support requested by the FAA to the COMSTAC. The WG determined that in order to provide timely input to the FAA on these regulatory issues, it would be advisable to provide an initial input for consideration of adoption in the draft NPRM as well as incremental inputs prior to release of the NPRM in May 1999. The RLV WG members have expressed a wide variety of opinions. These divergent opinions are reflected in the report by an indication of agreement or disagreement among industry members for the specific issues. Two basic approaches to regulation have been proposed; the tailored FAR and the "Nouveaux Regime". Both are presented in this report. In addition, there was a difference of opinion regarding the efficacy of using expectation of casualty as a measure of RLV safety. These opinions are also reflected in this report. The RLV WG will continue its current efforts to develop consensus, refine proposals and submit incremental inputs, culminating in a final RLV WG report in April 1999. It is anticipated that further incremental inputs will be provided to the FAA subsequent to NPRM release and throughout the scheduled period for comment, both by the RLV WG and individual industry members. These further RLV WG inputs will be identified as revisions to the final report. **(Kelly Space & Technology provided report integration. Contractor inputs for specific sections are indicated in the accompanying text)**

2.0 PHILOSOPHY OF RLV REGULATION
(Submitted by Kistler Aerospace)

The advent of reusable launch vehicles (RLVs) could transform humankind's use of space and restore the competitiveness of the United States in the international commercial launch industry.

The RLV Working Group accordingly urges the FAA to recognize this incipient revolution by adopting equally novel and flexible approaches to the regulation of RLVs.

2.1 Approach to Regulation of RLVs

In the view of the RLV Working Group, FAA regulation of RLVs should:

- Protect public safety;
- Address the special regulatory concerns of the new commercial RLV industry;
- Enable, not restrict, innovation and competition in RLV design, RLV modes of operation, and RLV system configurations; and
- Define a clear and simple path toward authorization to conduct test and commercial flight operations.

2.1a. Special regulatory concerns of the new commercial RLV industry

The advent of RLVs represents a sharp break from the history of aircraft and launch vehicles, demanding a sharp break from conventional regulation.

Reusable launch vehicles:

- will reduce substantially the cost of access to space, and thus constitute an enabling technology that will make possible new commercial uses of near space;

- are being developed in large part by small, entrepreneurial ventures using private financing (not government funds), like the early days of aviation, but unlike the development of expendable launch vehicles (ELVs);

- will re-enter and land for re-use in multiple flights, akin to aircraft, but unlike ELVs;

- are capable of operation in both the atmosphere and on orbit, unlike aircraft, but like ELVs;

- are capable of operation without elaborate ground systems, like aircraft, but unlike ELVs;

- will demonstrate their capabilities and reliability through repeated use, like aircraft, but unlike ELVs; and

- will make possible routine, short notice launch of payloads into orbit, unlike anything before them.

The RLV Working Group believes it essential that the FAA recognize and address these unique attributes of RLVs in any regulatory regime it ultimately implements. RLVs are neither aircraft nor launch vehicles, but rather aerospace vehicles that will transform the delivery of a cargo to space into a pure transportation service.

As this Interim Report will reveal, participants in the RLV Working Group hold divergent views on the best approach to RLV regulation. There is unanimity, however, on at least one point: Without significant adaptation, reflexive extension of existing regulatory regimes, standards and approaches will fail to address the uniqueness of RLVs and will impede the development of the reusable launch industry in its infancy.

2.1a Special Regulatory Concerns of the New Commercial RLV Industry (Submitted by Rotary Rocket)

Industry Regulatory Environment

At the start of this century, when the aviation industry was in its infancy, aircraft designs for various applications were relatively undefined and radically new vehicles were introduced with great frequency. Standard regulations and aircraft certification did not exist and flying was considered a dangerous activity.

About 23 years after Kitty Hawk, the Aeronautical Branch of the Department of Commerce, the predecessor to the Federal Aviation Administration (FAA), was established to oversee the aviation industry and promote the safety of the public, passengers and crew of commercial aircraft. The first aircraft certification[1] took place in 1927 though it was not until 1965 that Federal Aviation Regulation (FAR) 25, the primary standard for commercial aircraft design, was written. In other words, it took over half a century before enough standardization had occurred among aircraft developers to create an unbiased set of minimum design requirements for licensing purposes. It is interesting to note that by that time, over thirty percent of the U.S. population had already flown on a commercial aircraft.

The space transportation industry is in the same state today, as aviation was in the earlier part of the century—in an experimental stage, undergoing tremendous change.

Government funded, expendable launch vehicles (ELVs) have been the main method of getting to space since the industry's beginnings in 1957. The industry is now commercializing at a rapid pace with the passing of the Commercial Space Act and with strong growth in satellite telecom applications and other markets. The financial industry has recognized these trends and funds are slowly being made available for private space transportation ventures. Specifically, entrepreneurial companies are now introducing a wide variety of designs for reusable launch vehicles (RLVs) with a focus on substantially reducing the cost of access to space. Many of these reusable rockets will operate like aircraft, flying on missions to space, delivering cargo, and returning to Earth to repeat the process again and again. A regulatory environment to ensure the operational safety of these new systems needs to be established.

Launch Vehicle Safety

For the operation of ballistic missile-derived ELVs, the safety of the public has been protected through the use of launch site range safety standards and flight termination systems (FTS). With serious attention

[1] FAA Historical Chronology, 1926-1996. Available directly from the FAA web site at http://www.faa.gov/docs/b-chron.doc

paid to the vehicle destruct system, the design and manufacture of the rest of the vehicle has been able to continue with less focus on safety. Furthermore, by their very nature, ELVs cannot be properly flight-tested, putting developers in a difficult position in terms of proving their systems in flight. The result is that a new ELV design faces a 50-50 chance of failure[2] on its initial launch.

Range safety standards restrict launches to flights over uninhabited areas, usually the open sea. In the case of any vehicle problem, detonation by the range safety official is always an option. In addition, launch over the open sea allows staging materials to be dumped.

For a variety of reasons, RLVs will not utilize FTS as a safety measure. RLVs will operate like aircraft with abort scenarios; in some cases the RLV will be manned. With such a large variety of proposed vehicles in design and so little reusable rocket experience available, the industry is clearly not ready for aircraft-like certification procedures. RLVs will therefore require a different approach and a creative solution for the regulatory environment.

RLV Regulatory Environment

Within the FAA, the Associate Administrator for Regulation and Certification (AVR) has responsibility over aircraft, while the Associate Administrator of Commercial Space Transportation (AST) covers responsibility for launch vehicles. AST's role has recently been expanded to encompass the operation of RLVs.

Rotary Rocket Company and other industry participants are working with AST to draft regulations that take into account the fledgling state of this industry and support its growth and development. It is clear to those involved that too restrictive a regulatory regime could either bind the creative aspects of a company's particular RLV design, or delay a project and put the backing company out of business. Clearly, however, the safety of the public cannot be compromised and an environment that allows for the safe operations of new vehicles while the industry matures is the common goal of all involved.

Within this group of industry and FAA participants, several different approaches to regulating the operation of RLVs have been proposed. A few organizations have suggested the use of RLV-specific certification procedures. As a variation to this, others believe that aircraft FARs should

[2] All of the new launch vehicles that have been introduced in the last five years have failed at least once. Included in these are the Delta 3, Ariane 5, Lockheed Martin's Athena, the Pegasus XL, China's Long March CZ-3B, and Brazil's VLS. Source: Aviation Week & Space Technology, page 131, January 11, 1999.

be applied to space vehicles. Although on a high-level basis given some effort RLVs could be worked into the structure of the FARs, the detailed lower level aircraft-specific FARs are not relevant to RLVs. In either case the problem remains the same, both ignore the industry's early stage of evolution. Before aircraft-like certification procedures can be properly established, a mature industry and relevant RLV operational data is necessary.

A different proposal being considered by the group is a "holistic approach" to examine the proposed RLV design. Arguing that because the vehicle developer has the highest motivation to develop a safe vehicle, design documentation should be used as the primary source of licensing material. Focus can then be put on the questions: Is it designed to be safe?, Is it built as designed?, and Is it operated safely? to assess each RLVs design. Although this approach helps to create an intermediary step towards full certification, it still does not equip the regulatory authorities with the ability to compare the estimated risk levels of various RLVs, or compare with other activities of risk for the general public.

Casualty expectation analysis[3] (CEA), the process currently used for ELV licensing, can however, be applied in an unbiased manner to evaluate the risk of any proposed RLV design. A simplified format of this analysis can identify possibilities for system failures, assign a probability to the occurrence of each, and estimate the level of lethality of an occurrence. Lethality is assessed by estimating the level of debris from a failure and correlating it with the population density in the area of the flight path. Appendix A has further details outlining the process.

Applying CEA to RLVs does introduce some challenge to the process because of the higher level of system functionality. RLVs will have abort modes in place of the FTS systems of ELVs. Each of the vehicle's system abort paths will need to be examined to estimate the overall level of risk properly. A second major difference is that by definition RLVs fly more than once and the probability of failure will change over the life of the vehicle[4]. Attention has also been focused on the fact that without statistically accurate data on system probability of failure, accurate estimation of casualty expectation is difficult.

The bottom line is that CEA is a well-defined process for "estimating" and assessing operational risk. The result of which is comparable to other public activities such as taking a walk, racing a car or flying in a plane. It can be applied in the short term and can be used effectively as a guideline

[3] Refer to Appendix A for details, referenced from [3] and [4].
[4] Refer to the discussion on the Roton Maintenance Program in Section 9.

in the RLV licensing process for assessing the large variety of designs that are being proposed until operational data is gathered and RLV designs mature.

Recommended Approach to Licensing

Understanding that RLV development companies have a strong motivation to ensure the safe operation of their reusable vehicles, in the short term they should focus on designing reusable launch systems that reduce the expected level of operational casualties. The following is an outline of a possible approach:

1. Development companies use risk management tools[5] to design their vehicles, FMECA, PRA, ORM.
2. Design documentation can be used to assess operational risk for defined flight envelopes using a process similar to the expected casualty analysis applied to ELVs.
3. Compare the estimated level of risk to other activities and determine if an operating license is appropriate.

The insurance industry can also be used as a secondary tool to assess and cover the remaining risk for an RLV program. In order to determine the appropriate rate charged to insure the operation of an RLV, the insurer will also need to examine the vehicle design. Scrutiny of the engineering data and assessment of the project risk will occur a second time.

By licensing RLV operations in this way, designs can develop and mature and operational flight data can be accumulated in a relatively safe environment where the pubic is not subjected to “out-of-the-ordinary” risk. In the long term as the industry matures, aircraft-style certification procedures can slowly be developed as the data become available to create experience-based regulations and standards. This process can be encouraged through the collaboration of FAA and industry personnel.

Conclusions

The space transportation industry is undergoing tremendous change with the introduction of the first reusable launch vehicles. In attempts to significantly lower the cost of access to space, some of the established aerospace firms and a handful of entrepreneurial startups are pursuing a large variety of vehicle designs. These industry players are working with

[5] Failure Modes and Effects Criticality Analysis (FMECA) is a qualitative assessment of risk that is essentially a bottom-up approach. Each component is analyzed and its failure modes are determined. The effect of the failure on other systems and the entire vehicle is then determined. Probability Risk Assessment (PRA) is a top-down approach that first identifies a possible failure mode of the whole system and then examines ways this may occur and traces back to arrive at the fault or error that causes the result. Probabilities are then assigned to each fault to determine the overall risk for the vehicle.

the FAA to help define an appropriate regime to regulate the operation of these new vehicles in an unbiased fashion. The common goal of this group is to define a new licensing process for RLVs that will foster this promising new industry while ensuring the safety of the public.

With the industry at such an early stage of maturity, the application of aviation-style certification procedures is widely viewed as inappropriate. Although some industry participants are suggesting approaches that are partial or adapted certification procedures with a different name, these would be time consuming to define and do not provide an assessment of operational risk that allows for comparability between RLVs and other industries.

After considering the structure and state of the nascent RLV industry, it is important that the regulatory regime implemented initially provide an environment that has the following characteristics:

1. Certainty – a clear navigable path to licensing
2. Flexibility – the ability to apply equally to any RLV design as well as to adapt to the variety of testing and development philosophies that exist
3. Timeliness – an expeditious procedure

In the short term, casualty expectation analysis can be used effectively to provide an unbiased approach to risk assessment for the wide variety of RLVs currently being introduced. The procedure is already in use with ELVs and can therefore be rapidly adapted to take into account the unique characteristics of RLVs. In the mid-term, the experience of the space and aviation industries can be carefully adapted to the RLV industry with appropriate modifications to begin defining certification procedures. This can be effectively accomplished with a task group of FAA and industry participants. In the long-term, these modified regulations can be combined with the flight experience of licensed operating RLV manufacturers and an experience-based certification environment will be the result.

2.1b Need for clear, simple path toward licensing (Submitted by Kistler Aerospace)

As an emerging industry, RLV developers need a clear and simple path toward FAA authorization for test flights and for commercial operations. A complex or unduly burdensome regulatory structure will deter innovation, new industry entrants, competition and investment.

Congress shares this objective. In enacting the U.S. commercial space law, the first two purposes identified by Congress were:

- "To promote economic growth and entrepreneurial activity through use of the space environment for peaceful purposes;" and

- "To encourage the United States private sector to provide launch vehicles and associated services by … simplifying and expediting the issuance and transfer of commercial launch licenses."[6]

The RLV Working Group encourages the FAA to develop an RLV regulatory regime that simplifies and expedites, not complicates and hinders the development of the emerging RLV industry.

2.2 "Licensing" versus "Certification"

Participants in the RLV Working Group differed over whether FAA authorization of RLV operations should adapt the broad framework of "licensing" as now used for ELVs or "certification" as now used for aircraft.

2.2a. Arguments in favor of "licensing"

In the view of certain participants of the RLV Working Group,[7] the broad legal framework of an RLV license is the preferred model.

Licensing:

- permits the applicant to work with the FAA to define the regulatory requirements for its vehicle design, mode of operations and system configuration;

- allows flexibility and innovation in design, mode of operations, and system configuration;

- can accommodate vehicle operations and spaceport operations; and

- is the form of legal authorization for launch activities prescribed by Congress in the commercial space law.

Certification, in contrast, would force the FAA to develop standards or criteria to which an applicant would be required to certify. Certification inevitably would restrict flexibility, innovation and competition by placing

[6] 49 U.S.C. 70101(b)(1) & (2).

[7] The following RLV Working Group participants subscribe to this section: Kistler Aerospace Corporation, [others?].

the FAA, rather than industry members, in the role of selecting parameters for vehicle design. That consequence ultimately could hinder the development of the RLV industry.

Further, the mode of operation of a vehicle, whether on the ground, in the air and in space, as well as the configuration of the spaceport and launch system, are equally important considerations. They equally affect safety, operating costs, development costs, launch pricing, and other aspects of providing a commercial launch service. In recognition of the novelty and uniqueness of RLVs, the FAA should enable innovation in RLV modes of operations and system configuration as well as vehicle design. Licensing also is a more flexible legal instrument in the regulation of these aspects of RLV systems.

Finally, certification is not the legally prescribed form of regulation for vehicles capable of operation in space. The absence of a clear legal basis for certification of RLVs could delay the development of RLV regulations, and thus the clear and simple path to flight authorization needed by the emerging RLV industry.

2.2b Arguments in Favor of "Certification" (Submitted by Space Access)

The current buzzword in the launch industry is aircraft like operations. This philosophy is evident in the NASA X-33 program and in the USAF goals for military space operations in the future. Several new commercial launch vehicles are proposing aircraft like operations for their vehicles. An over-riding criterion of the FAA AST office is to protect the health and safety of the US public and this has been achieved in the US airline industry. With so much talk about aircraft like operations, the US airline industry was analyzed to look at their characteristics and evaluate if the airline model is applicable to the commercial launch industry. Figure 1 shows major areas of difference in the two industries.

U.S. Industry Comparison
Airline to Commercial Launch

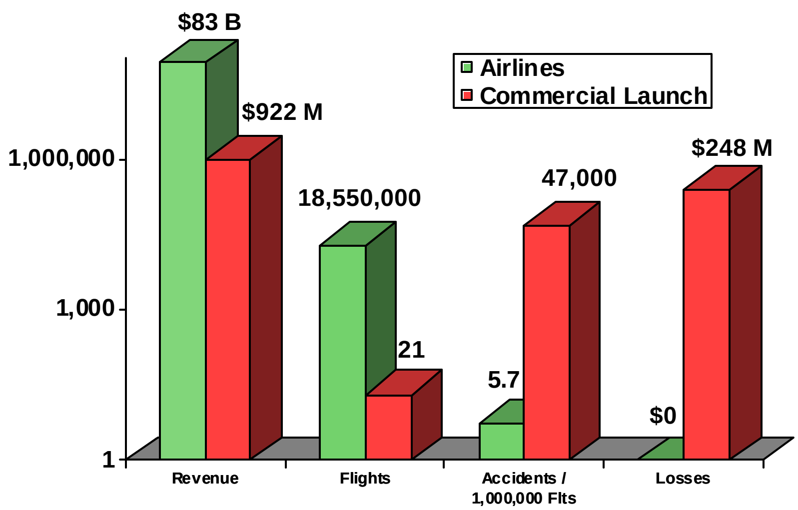

Figure 1

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Data gathered from multiple sources. It is especially noteworthy to compare the flight rates, accidents and loss rates. If the US commercial launch industry is to grow significantly, it must do something to cut losses which are directly tied to accident or failure rates. Figures 2 and 3 show the accident and fatalities associated with both industries.

Industry Performance

- Characteristics of U.S. Airline Operations - 1997
  - Over 625,000,000 Passengers
  - 2 Public Fatalities — P_{pf} = 1.08 x 10^{-7} / Flt Hr
  - 92 Crew/Passenger Fatalities — $P_{c/pf}$ = 5.07 x 10^{-6} / Flt Hr
  - 65 Accidents / 11,455,000 flights — P_a = 5.7 x 10^{-6} / Flight
  - Passenger Casualties — P_c = 3.68 x 10^{-8} / Flight*
    - Passenger Serious Injuries / Enplanements
      - Reference NTSB Table 3
  - Public Expected Casualties — E_c = 1.75 x 10^{-7} / Flight**
    - Public Fatalities multiplied by 200 / Number of Flights
      - Reference EWR 127-1 Appendix 1D Notes

    (Approximately the average number of casualties (at least one-day disability) experienced in the US for each accident fatality experienced)

*** 815 Times better than 30 X 10-6** ****171 times better than 30 x 10-6**

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Figure 2

Industry Performance

- Characteristics of U.S. Commercial Launch Vehicles - 1998
  - $ 922 Million Revenue
  - $ 248 Million insured losses — Loss = 27%
  - 0 Passengers
  - 0 Public Fatalities — P_{pf} = 0 / Flight
  - 0 Crew/Passenger Fatalities — $P_{c/pf}$ = 0 / Flight
  - 1 Accident / 21 Flights — P_a = 4.7 x 10^{-2} / Flight*
  - New Vehicle Failures — P_f = 4.0 x 10^{-1} / Flight

*1,566 Times worse than 30 x 10-6

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Figure 3

The Existing criteria for commercial launch vehicles for accidents is an E_c criteria of 30 x 10^{-6}. The U.S. airline industry achieved no fatal accidents in 1998 which is even better than the numbers shown in Figure 2, NTSB preliminary data for 1997. The US Airline industry achieved safety levels 815 times better than existing launch vehicle criteria. It should be noted that the launch industry achieved its objectives of limited public casualties but this criteria alone has done nothing to promote a lower accident rate. Figure 3 shows that if these vehicles were crewed or had passengers, they are 1,566 times worse than the required Ec level. The calculation was done in the same manner as the calculation in Table 1D-1 of EWR 127-1 which uses fatalities multiplied by 200, approximately the average number of casualties (at least one-day disability) experienced in the US for each accident fatality experienced.

Industry Safety Experience

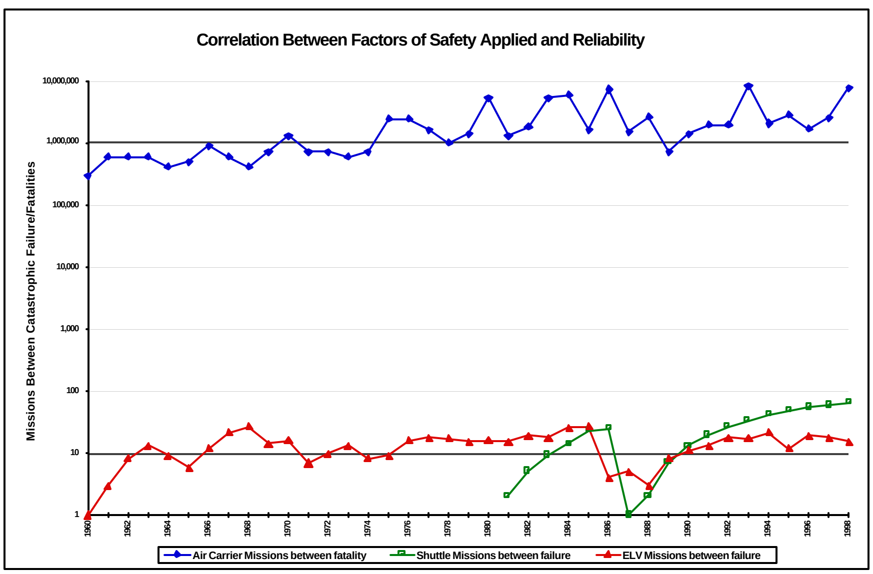

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Figure 4

Figure 4 is a comparison of the two industries looking at the number of missions between failures. It shows that the airline industry is five orders of magnitude better than commercial launch. The Space Shuttle is considered a special case of launch vehicle since it was designed with aircraft criteria in mind but did not achieve the factors of safety originally planned. It has used Ec criteria to protect the public and this resulted in no public fatalities. The one accident did result in the loss of life for the crew and many problems were subsequently fixed before flight resumed. Significant is the fact that the vehicle had enough margin in the design to allow the implementation of engineering changes and the addition of systems, such as crew egress, before flight resumed. As is seen the safe flight rate is rapidly surpassing the ELV industry standard. Any future

RLV should at least emulate the ability of the Space Shuttle to find and fix problems during the course of its life cycle.

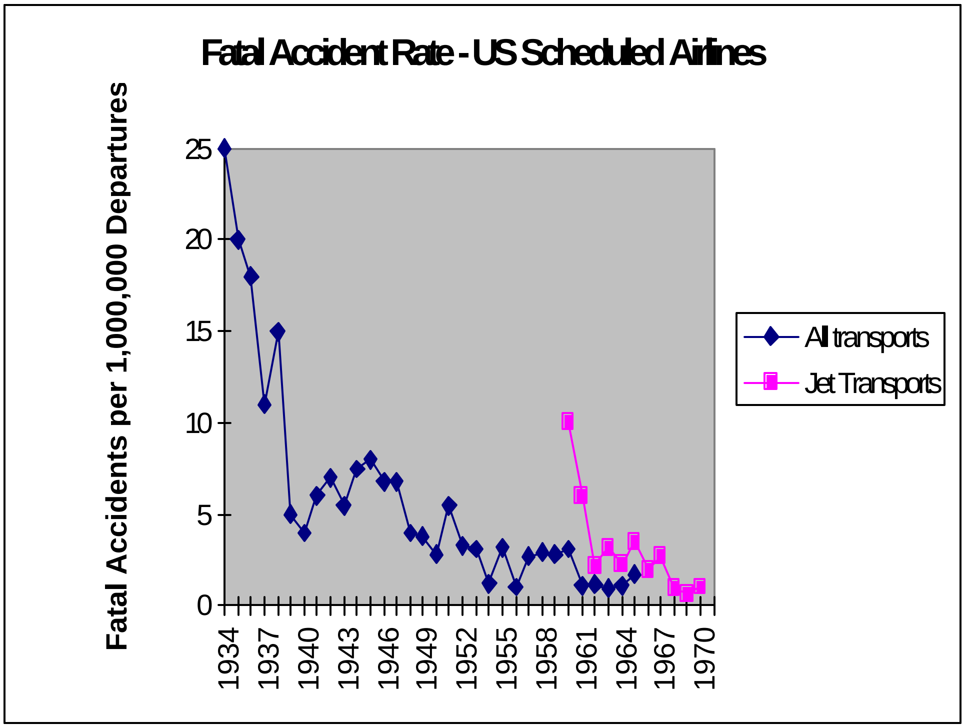

Figure 5

The airline industry has not always had such a low accident rate as Figure 5 shows transport aircraft history from the 1930s. It is important to see, with the introduction of a new form of propulsion, the safety levels established industry wide were achieved again quickly. The 1997 rate from the NTSB is 0.3 fatal accidents per mission departures. These jet transport aircraft used the same FAR Certification foundation and process established by the FAA that allowed them to quickly find and fix problems. It would be assumed that the FAA process has worked and directly results in the desired levels of safety. What is shocking is that the FAR Certification process does not dictate any accident level or casualty criteria for the public at large but has achieved significant improvement over the years.

Figure 6 shows the experience with new commercial launch vehicles. As the AST office has suggested the experience with new launch vehicles is less than spectacular. Of significant concern would be if these vehicles were manned for the first three flights. Experience in the industry is not even a good indicator of success since the first flight of the newest commercial launch vehicle, the Delta III, failed on it's maiden flight. As Figure 4 indicates there has been no significant improvement in the launch industry accident rate since we first began in the 1960's. Figure 6 confirms the learning curve has not improved the early success of new vehicles like the airline industry has achieved for large transport category aircraft such as the most recent Boeing 777. This aircraft is still accident free with thousands of departures to date and tens of thousands passengers flown.

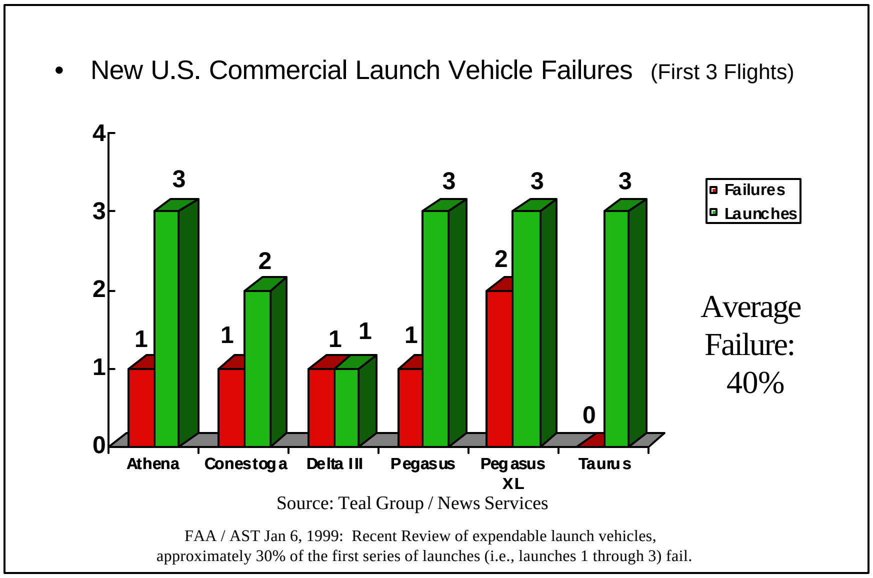

Figure 6

Looking to the FAR Certification methodology used in the airline industry may give some indication of how the launch industry could improve their accident rate and begin to think about achieving aircraft like operations. The Federal Aviation Regulations (FARs) are a large body of law that describe all aspects of aircraft operations. Figure 7 gives a quick summary of the major areas which are felt to apply to commercial launch vehicles. These include the Airworthiness Standards that are the body of knowledge developed over almost 80 years of human flight. It would be assumed that if one were to go back to study all aviation accidents, a continually improving trend would be seen. The standards describe how to demonstrate acceptable flight characteristics, which include performance on takeoff and landing, controllability and maneuverability, trim and stalls. An aircraft must be flown into almost all regions of possible flight to ensure no adverse flight characteristics are evident. This is achieved by an extensive flight test program. The structure is dictated to have a factor of safety of 1.5. During the design and construction of transport aircraft, special care is established to select material able to consistently handle the loads and environments to which they will be exposed. The process used for manufacturing, especially if multiple aircraft are produced, must be qualified so that quality is ensured. The equipment and systems are checked to see if they meet the requirements for the job, and special equipment such as pressurized compartments must meet higher loading standards based on experience with bursts and other failures. When the entire vehicle is characterized, then operating limits are established to keep pilots well inside those limits. The FARs then look at the operators of these aircraft and also at the environments in which they operate. Safe practices are established for both. The FAR process covers aircraft from design maturity into complete complex operations, as well as the people involved in the process.

- Federal Aircraft Regulation Process
  - Measurable Airworthiness Standards
    - Demonstrable Flight Characteristics
      - Performance, Controllability, Trim, Stalls
    - Structure Capability
      - Factors of Safety
    - Design and Construction
      - Characterization of Materials
    - Equipment and Systems
      - Pressurized vessels
    - Operating Limits
      - Speeds, Center of Gravity, Weights, Altitudes
  - Operator Qualifications
    - Training, Currency, Medical
  - Flight Rules
    - Airspace, right-of-way, Pressurization, Oxygen, Lights

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Figure 7

If the basic concepts of the FAR Certification process are applied to the commercial launch industry, Figure 8 summarizes that most accidents are caused by the lack of demonstrable flight characteristics (i.e., a lack of a complete flight test envelope expansion program). Design and equipment failures are not usually solved by redundancy because of system weight problems on launch vehicles, and all these lead to structural failure of the system since it does not have the structural factor of safety to allow failure of even one component. Ultimately, the vehicle breaks or is destroyed because it cannot be recovered.

Figure 9 shows the level of care taken in material characterization for aircraft structure and components. For non-redundant structure the material must pass 99% of specimen testing at a 95% Confidence level. If structure is redundant than the criteria is relaxed to 90% at a 95% Confidence level. New materials are not used until they have been proven to withstand the rigors of flight.

Accident Causes

- FAR Guidelines Applied to Launch Vehicles
  - Accidents not caused by:
    - Flight Rules
      - Airspace problems, Mid-Air Collision, Right-of-Way
    - Operators
      - Highly trained, current, and qualified
      - No operator caused accidents
    - Operating Limits
      - Limits not intentionally violated
  - Accidents caused by:
    - Demonstratable Flight Characteristics
      - Lack of Envelope Expansion Flight Test
    - Design and Construction, Equipment and Systems
      - Material flaws in structure or equipment, Non-redundant
    - Structural Failure
      - Limit Loads exceeded

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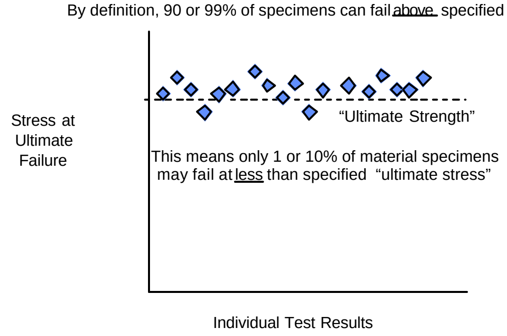
Figure 8

Conservative Approach Specified by Federal Aviation Accommodates Variability in Material

By definition, 90 or 99% of specimens can fail <u>above</u> specified "ultimate strength"



90 or 99% of Material Tests Must Pass at 95% Confidence Level

Figure 9

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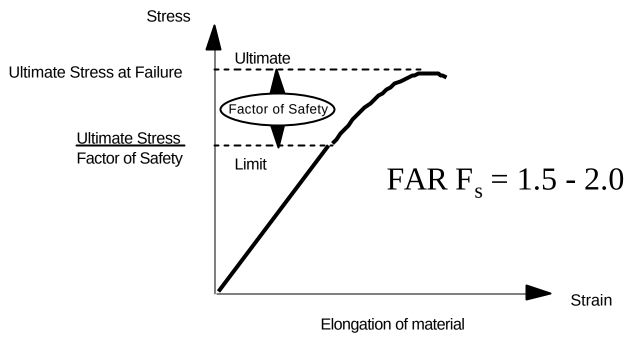
Structural factors of safety do not always directly lead to failures as the stress-strain depiction of Figure 10 shows, but it is this margin of safety built in throughout the vehicle that allows it to continue flight after a failure and recover safely, allowing the problem to be fixed. Margins of safety in the 50-100% range are common and must be adopted in the launch industry if any progress is to be made.

Importance of Conservative Factors of Safety



Margin of Safety = 50% to 100%

Figure 10

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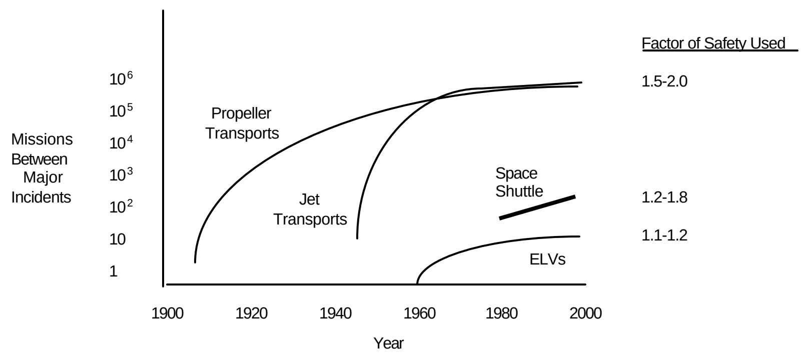
The FAR process uses historical information to account for past failures and provide redundant equipment and systems. Well-characterized materials take into account the variability of material properties by doing extensive coupon testing required of the certification process. It requires quality and maturity in the manufacturing process. The use of conservative factors of safety and design margins accounts for the unknowns on both new and aging flight vehicles. If the FAR Certification process is applied to launch vehicles then we can have vehicles that will not fail routinely and if a failure occurs then ample margin exists to allow fixing the problem and resuming safe flight.

If we look at the composite of aircraft and launch vehicle accident history and associate their factors of safety as they are known to exist, then a clear picture emerges which says we can no longer expect the failure rate to change significantly until the rules for design and operation are changed. Figure 11 graphically shows the difference in trend lines and why an aircraft model must be proposed for the launch industry, especially if human lives are at risk.

Correlation between Factors of Safety Applied and Reliability



Over time, use of conservative Factors of Safety enables orders of magnitude better reliability:

- Meeting FARs results in nearly "Six Sigma" quality in system reliability
- Less conservative Factors of Safety yields only "One to Two Sigma"

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Figure 11

Figure 12 shows what is proposed for RLV industry safety and regulation. The existing Ec criteria have worked well to provide for public safety at federal ranges. Now is the time to move clearly towards FAR Certification. The Ec criteria should be continued until launch vehicles show they comply with the FAR process. If certain flight regimes of launch vehicles currently meet FAR Certification and the remaining FAR guidance then the Ec criteria should not further restrict operations. The Pegasus vehicle is a classic case where crew safety is provided by the FAR Certification process and has achieved no accidents involving the crew, even though the Pegasus vehicle has failed several times. This vehicle is operated at times other than for launch as a large transport category aircraft. Within the FAR Airworthiness standards there are already provisions for Rocket Standby Power. These provisions need to be expanded to cover rocket power throughout the flight envelope and not just for standby use.

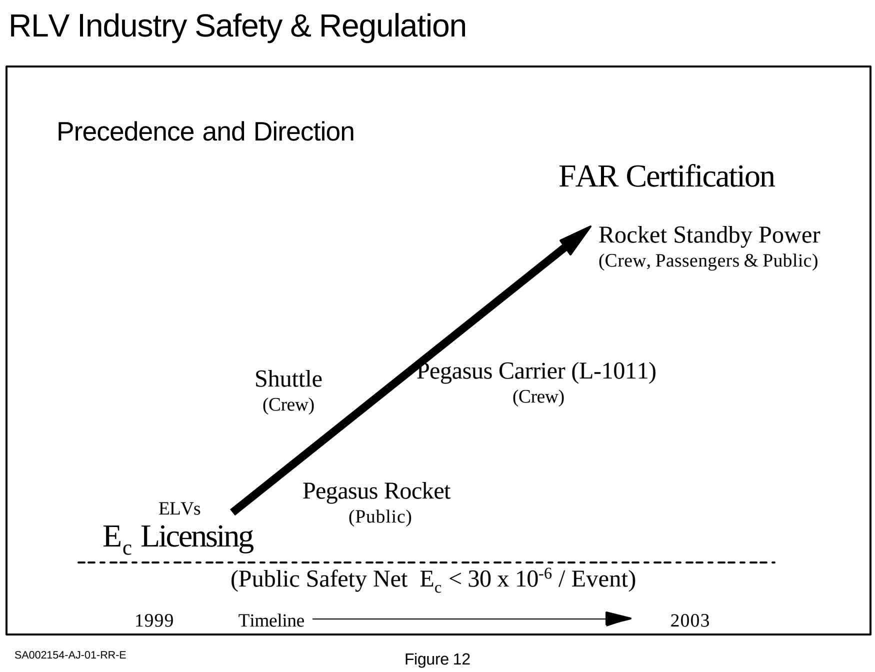

Figure 12

If the FAR process is adopted, then accidents and flight safety are enhanced from existing launch vehicle levels of 4.7×10^{-2} to aircraft levels of 5.7×10^{-6}, Figure 13. This is the only way to achieve public health and safety if over-flight is contemplated. Aircraft levels of safety and reliability are achievable over the life cycle of the system. Accidents might occur, but the system should start out with very few failures that result in catastrophic loss, and those failures can be fixed or mitigated rapidly, and the safe flight of the vehicle resumed. If accidents are reduced then the losses the industry faced in 1998 could go from a 27% range to hopefully someday 0% as the airlines just achieved in 1998.

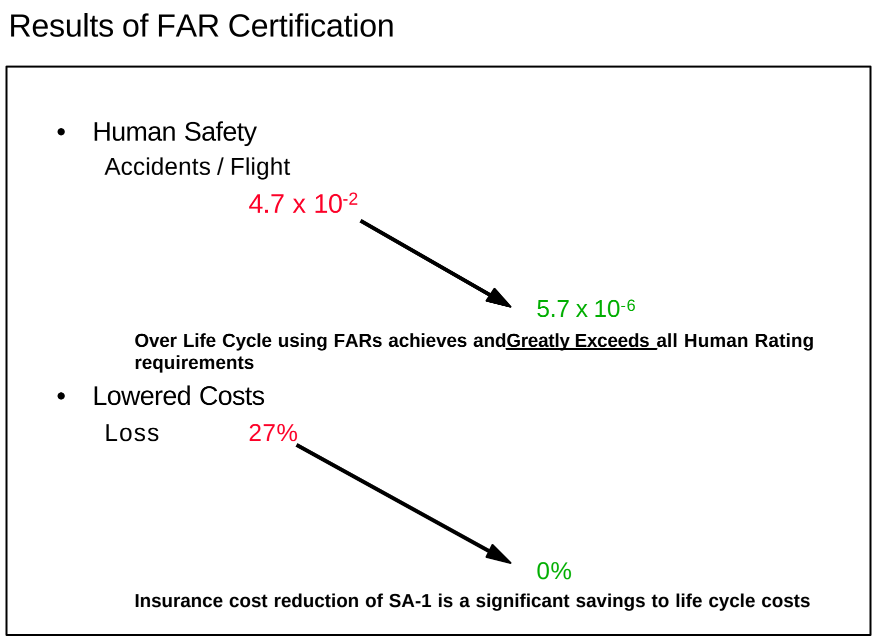

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Figure 13

Adopting an aircraft model for design, vehicle manufacture and testing, and complete operations under aircraft-based standards, such as the Federal Aviation Regulations for Transport Aircraft, will ultimately achieve the results desired by the FAA and will provide for a healthy launch industry in the US.

(End of Space Access submission)

The following is a paper addressing space-worthiness standards for RLVs. Although not written specifically as an argument in favor of certification, the paper addresses many of those issues most often advanced in favor of certification.

LIABILITY ISSUES AND THE DERIVATION OF REUSABLE LAUNCH VEHICLE SPACE-WORTHINESS STANDARDS

by

René J. Rey

Independent Study Project, SpSt 997
University of North Dakota, Grand Forks
December 4, 1998

Liability Issues and the Derivation of Reusable Launch Vehicle Space-worthiness Standards

Abstract

Aircraft are designed to meet airworthiness and vehicle certification requirements in accordance with well established national and international standards that have evolved over the past 70 years.[8] These standards are designed to promote safety and reliability in aircraft systems; and apply to all aircraft designs, whether they are operational or developmental.

The emergence of commercial reusable launch vehicle (RLV) systems, on the other hand, will not have the benefit of specific, codified standards. Yet, developmental and operational RLVs are expected to operate like conventional aircraft from multiple sites around the Earth, carry cargo, and over-fly population centers across a broad range of azimuths. And, like aircraft, RLVs will come in a variety of shapes and sizes that employ a wide range of operational concepts. These concepts include single-stage-to-orbit (SSTO) and multi-stage-to-orbit (MSTO) vehicles, each incorporating a unique combination of structure, propulsion, and flight profile to achieve orbital injection requirements (while carrying a meaningful payload mass).

However, it is doubtful that many first generation RLV systems will achieve their performance objectives without taking some major short-cuts that could (and undoubtedly will) compromise the same safety and reliability standards that commercial air transports are required to adhere to. In fact, maximum allowable dry-mass-fractions for RLVs using current technology propulsion systems, may preclude incorporation of the robust structures and subsystems necessary for *reliable*, reusable operations involving *the* ***safe*** *over-flight of population centers*. Hence, certification and licensing standards should not be tailored to accommodate the uniqueness of each RLV design concept, as proposed by some of today's hopeful developers and operators. Rather, an RLV design that will achieve aircraft-like operations *without* compromising aircraft safety standards should be established as the benchmark upon which the legal regime for *all current and follow-on systems* will be based.

Proposed SSTO and MSTO concepts, then, should be certificated against credible *space-worthiness* standards (derived, conceptually, from existing airworthiness and flight vehicle certification requirements) prior to licensing. These standards must not only address the liability principles embodied in domestic and international air and space law, but accommodate product liability and indemnification as well. On the one hand, the compliance costs associated with an overly stringent (or arbitrary) application of existing airworthiness standards (as defined in the Federal Aviation Regulations (FARs)) will, most certainly, strangle the nascent RLV industry. On the other hand, a "gerrymandering" approach to certification and licensing could doom the RLV industry as well, through the high cost of litigation resulting from any accidents.

[8] Beginning with the Warsaw Convention, which was signed in 1929.

With the foregoing in mind, this paper will examine the potential legal liabilities associated with RLV operations (e.g., ground processing, launch, on-orbit, landing, abort, etc.) and "cargo" transport. Once these liabilities have been defined, a method for ensuring an acceptable level of RLV space-worthiness (i.e., minimum standards that mitigate the liabilities defined) can be derived—which in turn will allow the *legal viability* of competing RLV designs to be properly assessed.

Background

The focus of many present-day reusable launch vehicle concepts revolves around the technical performance, ease of manufacture and the minimal amount of testing and analysis required to "validate" a flight vehicle system. The primary impetus for this focus is the RLV operator's need to drive launch costs down to less than $1,000 per payload pound to orbit,[9] which in turn forces many tradeoffs among a flight vehicle's subsystems, propulsion, structure and design for operability. However, design tradeoffs must not only take into account the technical performance issue of getting a specific payload mass into orbit; but also address the fact that "…the concept of low-cost immediately imposes the requirements of high usage rates and fast turnaround times with minimum maintenance."[10] Engineering reviews for most RLV development programs address system requirements, preliminary design and critical design milestones as the predominant criteria for determining whether their launch systems are "viable." However, these reviews fail to acknowledge the underlying theme of liability that is inherent in space launch vehicles that are designed to be operated and maintained like traditional high performance, heavy jet aircraft.

At the heart of a reusable launch vehicle's technical performance is its *dry mass fraction*, which is the ratio of an RLV's structural mass to its total mass (with a full propellant load and payload).[11] Due to the inherent limitations of state-of-the art propulsion systems, any increase in an RLV's dry mass fraction will directly reduce the payload mass it can deliver to orbit (which in turn has an affect on an RLV venture's revenue per flight). In order for an RLV to perform the same mission as an expendable launch vehicle, assure very high reliability and return to its spaceport for a quick turnaround, its dry mass must accommodate many additional requirements.[12] These

[9] "Lockheed-Martin has set a goal of building and operating [a] reusable launch vehicle, VentureStar, and charging customers less than $1,000 per pound for placing payloads into low Earth orbit." This goal appears to be pervasive throughout the RLV industry and NASA. **Source:** Marshall H. Kaplan, "The Reusable Launch Vehicle: Is the Stage Set?" *Launchspace Magazine* March 1997: 26.

[10] Kaplan, Launchspace 27.

[11] For example: VentureStar is projected to have a gross lift-off weight of 2,186,000 lbs, with a propellant load of 1,929,000 lbs. Hence, the propellant mass fraction is 88.2%, which leaves 11.8% for dry mass and payload. Assuming a payload mass fraction of 2.7%, this leaves a structural mass fraction of 9.1%. **Source:** Kaplan, Launchspace 27.

[12] "Current dry mass fractions for expendable launch vehicles fall into the range of about 10% to 13%. Without the introduction of new technologies, the addition of improvements for reusability must add an additional several per cent to these fractions." **Source:** Kaplan, Launchspace 29.

requirements include, but are not limited to: retro/maneuvering engines; additional propellants and tanks; return maneuvering structures and mechanisms; reentry thermal protection systems; reusability modifications to structures, engines, tanks and avionics; health monitoring systems; safe return-from-abort equipment; and landing gear/supports.[13] One way to offset the additional mass resulting from RLV-unique requirements is through the innovative use of composite materials, which in turn will add complexity to an RLV's fabrication processes and increase manufacturing costs. Another way is to develop new generation propulsion systems capable of producing the requisite thrust level and specific impulse parameters necessary to reduce an RLV's mass fraction to insignificance. However, reducing vehicle mass fractions is only one aspect of reducing an RLV's susceptibility to liability.

Imposing the requirements of *high usage rates* and *fast turnaround times with minimum maintenance* on reusable launch vehicles further exacerbates their dry mass growth propensities. This is because enhanced factors-of-safety, and higher levels of redundancy must now be designed into an RLV system to allow it to safely and reliably perform 100+ sorties between major overhauls.[14] Naturally, the only way to certify these criteria is through extensive flight testing, and the collection of time-age-cycle data on RLV subsystems, propulsion and structural components. Hence, it would appear that *high usage rates* and *fast turnaround times with minimum maintenance* are the predominant factors in assessing a reusable launch vehicle's exposure to liability. However, it is a combination of these attributes, an RLV's payload-to-orbit capabilities (as determined by the interaction of the vehicle mass fraction and propulsion performance) and its operational over-flight corridor(s)[15] that will determine a reusable launch vehicle's over-all exposure.

The key *operational over-flight corridor* contributors to an RLV's over-all liability exposure[16] include (but are not limited to):

- flight vehicle controllability, intact abort and emergency landings;
- departure/approach corridor deviations to designated flight paths;
- re-entry of customer payloads following flight vehicle separation; and
- the presence of damage-prevention mechanisms (passive and/or active).

Within the context of these contributors, the U.S. Federal Aviation Administration (FAA), Office of Commercial Space Transportation (AST), will currently license reusable launch vehicles based on whether they are (1) designed to be safe; (2) built to

[13] Kaplan, Launchspace 27.

[14] The operational goal of the Space Access Launch System, a fully reusable, three-stage to GTO system. **Source:** M. Wade, Vice President for Programs, Space Access, LLC.

[15] The overland corridor an RLV will use during the flight phases of takeoff, transition-to-orbit, mission operations (orbital and sub-orbital), re-entry and landing.

[16] "On the Earth and between the Earth and Earth orbits; and in Earth orbits" — see the section of this paper entitled: "Liability Doctrines Relevant to RLV Space-worthiness."

design; and (3) capable of safe operation.[17] There are no common space-worthiness standards against which different RLVs can be assessed—rather, it is up to the individual RLV operators to prove their vehicles are "safe" for flight.

Title 14 of the Code of Federal Regulations (CFR), Chapter III, contains the procedures and requirements that govern the authorization and supervision of all space activities conducted from United States territory, or by citizens of the United States.[18] These procedures and requirements examine four areas of concern that directly impact the potential liability of a reusable launch vehicle enterprise: site location safety, operating procedures accuracy, personnel qualifications and equipment adequacy.[19] In addition, RLV system safety and mission reviews are conducted.[20]

The safety review process is critical because the United States can be held liable for any damage incurred by the public or A third State (in accordance with the 1972 Liability Convention and the 1967 Outer Space Treaty).[21] The mission review process is also critical because it involves national security aspects, as well as "all other elements susceptible of interfering with the treaty obligations of the United States."[22] Specifically, "[mission review] is the procedure for identifying significant issues affecting United States interests and international obligations that may be associated with a proposed [RLV] launch."[23] The burden of proof for ascertaining whether a reusable launch vehicle poses a national security (or treaty obligation) concern clearly rests with the FAA/AST, and not the applicant.[24]

Current expendable launch vehicle and semi-reusable launch vehicle designs evolved under Government sponsorship, and are therefore, subject to space law only. For these designs, defined as *space objects*, space law only deals with the liability of the launching state, and neither airworthiness nor certification standards apply. First generation RLV developmental flights will also be subject to space law—but for the commercial RLV industry to evolve into a worldwide space transportation infrastructure,

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[17] From the Commercial Space Transportation Advisory Committee (COMSTAC) RLV Working Group meeting held at the AIAA offices in El Segundo, CA on September 30, 1998.

[18] Bruce Stockfish, "Space Transportation and the Need for a New International Legal and Institutional Regime," *Annals of Air and Space Law, Vol. XVII* (Montreal, Canada: ICASL McGill University, 1992) 331.

[19] Stockfish, Space 336.

[20] See 14 CFR, Chapter III, Part 415, Subpart B (Safety Review) and Subpart C (Mission Review).

[21] Valerie Kayser, "An Achievement of Domestic Space Law: U.S. Regulation of Private Commercial Launch Services," *Annals of Air and Space Law, Vol. XVI* (Montreal, Canada: ICASL McGill University, 1991) 350. —Also see the section entitled, "Liability Principles in Domestic and International Air and Space Law."

[22] Kayser, Achievement 361.

[23] 14 CFR, Chapter III, Part 415.21.

[24] See 14 CFR, Chapter III, Part 415.21.

the principles of space law alone (as it exists today) will no longer suffice. In addition to the liability principles inherent in domestic and international air and space law, product liability and indemnification issues must also be addressed—issues which are directly related to vehicle flightworthiness and certification.

Liability Principles in Domestic and International Air and Space Law

Liability in domestic and international air and space law deals with compensation for damage resulting from loss of life, personal injury, loss of property or damage to property.[25] There are three "classes" of damage:[26]

- damage to third parties on the surface of the earth;
- damage arising out of collisions; and
- damage to cargo.

The fundamental liability principles embodied in air and space law, and their relevance to these classes of damage, are summarized below:

In air law, liability is based partly on international treaties and partly on domestic law. The Rome Convention of 1952 and the Protocol to amend that Convention in 1978, regulate damage to third parties on the surface of the earth. Article I of the Convention states "that any person who suffers damage on the surface shall, upon proof that the damage was caused by an aircraft in flight or by any person or thing falling therefrom, be entitled to compensation."[27] Hence, the injured party does not need to prove fault. International treaties, however, do not cover provisions concerning collisions between two aircraft—instead; any claims must be adjudicated through domestic laws and courts.[28] In addition, there's a good chance that any collision claims will be based on fault liability, because the parties involved are subject to the same degree of hazard.[29] Finally, Chapter III, Article 18 of the Warsaw Convention establishes an air carrier's liability for damage to cargo. The legal basis for this liability is a *fault liability with a reversed burden of proof*, which means that the air carrier is not liable if all necessary measures were taken to avoid the damage.[30]

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[25] Stephen Gorove, *Developments in Space Law* (Dordrecht: Martinus Nijhoff Publishers, 1991) 224.

[26] Tanja L. Masson-Zwaan, "The Aerospace Plane: An Object at the Crossroads Between Air and Space Law," *Air and Space Law: De Lege Ferenda*, eds. T.L. Masson-Zwaan and P.M.J. Mendes de Leon (Dordrecht: Kluwer Academic Publishers, 1992) 255.

[27] Masson-Zwaan, Aerospace 256.

[28] However, the Warsaw Convention (an international treaty) would apply if all the conditions were met. For example, in the mid-1970's two airlines engaging in international flights collided on the runway in the Tenerife Airport (Spain). The Courts applied the Warsaw Convention to adjudicate the case. Also, Article 24 of the Rome Convention states that the "Convention shall not apply to damage caused to an aircraft in flight, or to persons or goods on board such aircraft."

[29] Masson-Zwaan, Aerospace 256.

[30] Masson-Zwaan, Aerospace 256.

Under space law, there are two international conventions dealing with the liability of "space objects." These conventions include the Convention on International Liability for Damage Caused by Space Objects ("Liability Convention"), March 29, 1972; and the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies ("Outer Space Treaty"), October 10, 1967. Article II of the Liability Convention states that the launching state is *absolutely* liable for damage to third parties on the surface of the earth, or to aircraft in flight. It does not, however, cover injury or damage to nationals of the launching State; nor does it preempt or limit any remedy that an injured party may have under his/her own State's law.[31] Article III of this Convention, on the other hand, provides for liability based on fault in the event of a collision between two spacecraft. In addition, a strict interpretation of Article III provides that fault liability is applicable to damaged cargo as long as the damage is caused by another space object.[32]

On the other hand, there are two provisions in the Outer Space Treaty that address liability. Article VII stipulates that the launching state is internationally liable for damage caused by a space object or its component parts.[33] Whereas, Article VI specifies that states bear international responsibility for national activities in outer space and for assuring that such activities are carried out in conformity with the provisions of the Outer Space Treaty.[34]

Reusable launch vehicle "space transportation activities" subject to liability within the purview of the Liability Convention and the Outer Space Treaty include those:[35]

- on the Earth and between the Earth and Earth orbits;
- in Earth orbits;
- between the Earth and inter-stellar space;
- in inter-stellar space;
- between the Earth and celestial bodies;
- on celestial bodies and between them and their orbits, in the solar system;
- in the orbits of celestial bodies; and
- between the Earth and deep space and in deep space.

However, the scope of this paper will be limited to the space-worthiness-related liability issues associated with RLV operations *on the Earth and between the Earth and Earth orbits*; and *in Earth orbits.*

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[31] Stockfish, Space 349.

[32] Masson-Zwaan, Aerospace 256.

[33] Gorove, Developments 244.

[34] Gorove, Developments 245.

[35] Henri A. Wassenbergh, "The Law of Commercial Space Activities," *Outlook on Space Law Over the Next 30 Years*, eds. G. Lafferranderie and D. Crowther (The Hague: Kluwer Law International, 1997) 183.

Given the preceding discussion, the question now becomes, to which legal regime's liability principles should reusable launch vehicle space-worthiness standards be subordinated? There are two schools of thought regarding this issue—the territorial approach and the functional approach. The territorial approach is based upon *the precise border between airspace and outer space*; whereas the functional approach is based upon *the function* of the RLV, which might be different in each mission.

The functional approach readily accommodates both air and space law by allowing a distinction between:

(1) delivery space flights or "launchings" (i.e., flights of RLVs transporting unmanned or manned space objects into/from outer space, bringing space objects into orbit, transporting people and goods to/from space stations, or to/from celestial bodies);
(2) outer space flights (between space stations); and
(3) transportation space flights (between points on the Earth and destinations in outer space or between points on the Earth via outer space).[36]

The territorial approach, on the other hand, relies upon the delimitation of outer space—an issue the United Nations Committee on the Peaceful Uses of Outer Space ("COPUOS") has formally considered since 1958.[37] Most of the ensuing discussion has been documented by the United Nations Secretariat in a background paper entitled, *The Question of Definition and/or the Delimitation of Outer Space*, which was published in 1970 (an addendum was later attached in 1977).[38] There are two camps debating the delimitation issue: the spatialists, who believe in the need for a geographical or territorial delimitation of airspace from outer space; and the "wait-and-seers," who fundamentally wish to wait and see where technology and legal analyses lead before making a firm decision.[39]

In support of the spatialist view, the Soviet Union (now the Commonwealth of Independent States) proposed the following working paper in 1979 and 1983:[40]

(1) The region above 110 kilometers altitude from the sea level of the earth is outer space;
(2) The boundary between airspace and outer space shall be subject to agreement among States and shall subsequently be established by a treaty at an altitude not exceeding 110 kilometers above sea level; and

[36] Wassenbergh, Law 183.

[37] F.K. Schwetje and D.E. Walsh, "Hypersonic Flight: The Need for a New Legal Regime," *Proceedings of the First International Conference on Hypersonic Flight in the 21st Century* (Grand Forks, North Dakota: University of North Dakota, 1988) 327.

[38] Bin Cheng, "The Legal Status of Outer Space and Relevant Issues: Delimitation of Outer Space and Definition of Peaceful Use," *11 Journal of Space Law* (University, Mississippi: University of Mississippi Law Center, 1983) 93.

[39] Cheng, Legal 94.

[40] Schwetje and Walsh, Hypersonic 327.

(3) Space objects or States shall retain the right to fly over the territory of other States at altitudes lower than 110 kilometers above sea level for the purpose of reaching orbit or returning to earth in the territory of the launching State.[41]

On the other hand, the United States, a key proponent of the "wait-and-seer" camp, advanced the following reasons for not actively seeking an immediate and final solution to the delimitation issue:

(1) The inability of most countries to monitor such an altitude frontier;
(2) The lack of adequate examination of the relevant scientific, legal, and political factors; and
(3) The possible inhibiting and even stifling effect of such a boundary on future efforts to explore and use outer space.[42]

Reusable launch vehicles, combining the attributes of aircraft and spacecraft, must readily accommodate the liability principles incumbent in both air and space law, which makes them more amenable to the functional approach. In the words of Judge Guillame of the International Court of Justice:

> The territorial approach is not a useful criterion to solve this matter because there still is no boundary between air and space…The functional approach is better suited, so that the use of the vehicle should be decisive, although this leaves the problem of multiple purpose missions…[43]

Liability Doctrines Relevant to RLV Space-worthiness

The doctrines of *absolute liability* and *product liability* are the most relevant to reusable launch vehicle space-worthiness standards. Within the purview of these doctrines there are at least three entities, which may be held liable: the launching state, the appropriate state party, and non-governmental entities (i.e., the RLV enterprise).[44] Since this paper is being written from a commercial RLV enterprise perspective, only the liability for a non-governmental entity will be addressed.

As previously mentioned, the reusable launch vehicle enterprise may be held liable under the Liability Convention, the Outer Space Treaty, or domestic law for damage caused by an RLV. The complex interaction of the applicable international and domestic laws governing liability are clearly portrayed in the following:

> The non-governmental user's liability under the Liability Convention and the liability provision of the Outer Space Treaty could result in [absolute] liability if the government is the launching state and if the liability is not waived. In such case the non-governmental user's liability would be indirect via the government which would be directly liable. The same would apply under the international responsibility provision of the Outer Space Treaty if the state is not a launching state but the "appropriate state party," most likely the state of nationality. In these cases, in the absence of a waiver, the non-governmental user would have to reimburse the government once the latter is held liable as a result of the

[41] Cheng, Legal 94.

[42] Cheng, Legal 94.

[43] Tanja L. Masson-Zwaan, "The Spaceplane and the Law," *19 Journal of Space Law* (University, Mississippi: University of Mississippi Law Center, 1991) 66.

[44] Gorove, Developments 224.

> non-governmental user's activity. The aggrieved party, whether a non-national, national or government, may seek recourse under domestic law and procedure.[45]

The basis for liability under domestic law is likely to be either negligence or strict liability—the standards for product liability. However, should a court regard the RLV operation, as ultra-hazardous, absolute liability will be imposed.[46]

Absolute Liability

The basis for absolute liability is *ultra-hazardous activity*, which is defined as "an act or conduct, not of common usage, which necessarily involves a risk of serious harm to the person or property of others which cannot be eliminated by the exercise of utmost care."[47] Absolute liability is a product of the machine age, whose evolution produced numerous instances of serious property damage and personal injury. As a result, it became necessary to place these losses "on those who, though free from negligence or tortious intent, had control over the instrumentality causing the harm and who, in most cases, were better able to foresee the possibility of financial loss and protect through insurance techniques against it."[48]

Similarly, strict liability involves injury to persons or property without regard to fault or negligence, arising from ultra-hazardous or abnormally dangerous activities, and must satisfy the following conditions:[49]

- the activity must involve a risk of serious harm to person or property;
- the activity cannot be performed without risk regardless of care; and
- the activity must be uncommon in the "area."

However, strict liability may also apply, within the purview of product liability, to defective or unreasonably dangerous products; provided the product reaches or affects the injured person or property without having been altered by another.[50]

The history for liability of damage to property caused by crashing aircraft may well be a harbinger for the course the law will take regarding reusable launch vehicle accidents. This precedent was established during the early days of aviation, when aircraft and balloon flights were held to be ultra-hazardous activities.[51] In *The Law of Aviation*, a treatise on air law written in 1938, Mr. Hotchkiss stated:

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[45] Gorove, Developments 228.

[46] Gorove, Developments 228.

[47] Andrew G. Haley, *Space Law and Government* (New York: Appleton-Century-Crofts, 1963) 234.

[48] Haley, Space 237-238.

[49] There are subtle differences between the terms "absolute liability" and "strict liability." In general, "absolute liability" is a standard used in Europe, whereas "strict liability" is a U.S. standard. It should be noted that the Liability Convention uses the term "absolute" which is generally understood to also mean "strict." However, for the purposes of this paper, further technical definition is unnecessary.

[50] *Black's Law Dictionary* (St. Paul, Minnesota: West Publishing Company, 1990).

[51] Haley, Space 238.

> It has been generally recognized that where an aircraft descends on a person or property on the ground beneath, or where objects thrown from the aircraft cause damage, the owner or operator of the aircraft should be held to the strictest accountability.[52]

During the time period immediately preceding this treatise, many states passed laws making an aircraft owner absolutely liable for any damage or injury caused by the crash of his aircraft. In fact, twenty-one states and territories in the United States adopted the Uniform Aeronautics Act in the period from 1920 to 1930.[53] Section 5 of this statute reads:

> The owner of every aircraft which is operated over the lands or waters of this state is absolutely liable for injuries to persons or property on the land or water beneath, caused by the ascent, descent or flight of the aircraft or the dropping or falling of any object therefrom, whether such owner was negligent or not, unless the injury is caused in whole or in part by the negligence of the person injured or the owner or bailee of the property injured.[54]

This statute aptly fits the flight operations of first-generation reusable launch vehicles. The complex interaction of rocket propulsion, structures, avionics and software—and the myriad possibilities for malfunction—naturally place RLV systems at great risk.

Hence, it is reasonable to expect that first-generation reusable launch vehicle operations will be viewed by the courts as being ultra-hazardous, and that RLV enterprises can expect to be held absolutely liable for any damages caused, even if they are free from negligence. A fairly recent, catastrophic launch vehicle accident comes to mind to support this view: the Xichang launch failure in January 1995. An excerpt from a "Causes of Action" analysis regarding this launch failure follows:

> Had the Xichang launch failure qualified as a Category II loss the launching States would be "absolutely liable" to the Chinese nationals killed or harmed [LC art. II]. Plaintiffs would not need to show any fault and arguably their contributory negligence or assumption of the risk, if any, would not be a defense. Because the failure is a Category I loss, the selected forum will have to decide if fault must be shown and whether the doctrine of res ipsa loquitur applies. Quite likely, the selected forum will decide that space activities in their present stage of development are an ultra-hazardous activity meriting application of a strict liability or absolute liability rule – unless the State's waiver of immunity statute bars suit based on strict liability against that defendant State. Causes of action may also include claims of product liability and nuisance. Applying a strict liability standard to a private company involved in the Xichang launch failure creates no problem. The manufacturers, subcontractors, and suppliers of the launch vehicle and satellite may all be target defendants.[55, 56]

[52] Haley, Space 238.

[53] Haley, Space 238.

[54] Haley, Space 238.

[55] R. Bender, *Space Transport Liability – National and International Aspects* (The Hague: Kluwer Law International, 1995) 343.

[56] "The Liability Convention establishes two basic rules (1) national law governs harm caused by space objects to those States cooperating in a space endeavor and to the nationals of those cooperating States (Category I cases) but (2) international law governs harm caused by space objects to those States not engaged in a common endeavor (Category II cases)." **Source:** Bender, Space Transport 3.

Product Liability

U.S. Aviation Product Liability Law comprises three *foundations for claims* categories which are differentiated by the requirements (e.g., willful misconduct, rightful claimants, etc.), and the legal consequences (e.g., scope of compensation, etc) of each case.[57] These categories include claims derived from *warranty*, *negligence* and *strict liability.*[58] Variations in national law on product liability, however, differ from jurisdiction to jurisdiction. Aviation product liability law relates to reusable launch vehicle space-worthiness because RLVs will have to be operated and maintained like the state-of-the-art jet aircraft in service today. Similarity in operations implies that a similar product liability regime will be applied as well. The following discussion concerning RLV product liability, however, is limited to negligence and strict liability in tort.

Negligence

In U.S. tort law an action in negligence against a manufacturer has been possible since 1916, when Judge Cardozo wrote his landmark opinion in *MacPherson v. Buick Motor Co.*:[59]

> We are dealing now with the liability of the manufacturer of the finished product, who puts it on the market to be used without inspection by its customers. If he is negligent, where danger is to be foreseen, a liability will follow…There is no break in the chain of cause and effect. In such circumstances, the presence of a known danger, attendant upon a known use, makes vigilance a duty.
>
> ***
>
> Precedents drawn from the days of travel by stagecoach do not fit the conditions of travel today. The principle that the danger must be imminent does not change, but the things subject to the principle do change. They are whatever the needs of life in a developing civilization require them to be.[60]

After *MacPherson*, within the law of product liability the concept of strict liability was developed, first in contract for breach of warranty, express or implied, and later strict liability in tort for physical harm to persons and tangible things.[61]

Liability for the negligence of a reusable launch vehicle enterprise can be invoked directly by a third party if the enterprise fails to take every reasonable measure to avoid

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[57] Jean-Michel Fobe, *Aviation Products Liability and Insurance in the EU* (Deventer: Kluwer Law and Taxation Publishers, 1994) 86.

[58] Fobe, Aviation 86.

[59] P.P.C. Haanappel, “Product Liability in Space Law,” *2 Houston Journal of International Law* (Houston, Texas: University of Houston Law Center, 1979) 59.

[60] Phillip D. Bostwick, “Liability of Aerospace Manufacturers: ‘MacPherson v. Buick’ Sputters into the Space Age,” *22 Journal of Space Law* (University, Mississippi: University of Mississippi Law Center, 1994) 76.

[61] Bostwick, Liability 76-77.

any foreseeable risk in the manufacture and handling of products. The prerequisites of liability are:[62]

1. a duty of care;
2. a breach of this duty;
3. an adequate causal connection between the damage sustained and the negligently constructed or operated product; and
4. damage sustained by the plaintiff.

Once these elements are met, the liability for negligence can include liability for improper design and faulty manufacturing, the duty of product control, and inadequate warning, instructions for use, etc.[63] In addition, U.S. aviation product liability law places considerable importance on the various sections of the "Restatement, Torts, Chapter 14, 'Liability of Persons Supplying Chattels for the Use of Others,' Paragraph 388-408,"[64] and compliance with the certification and airworthiness standards of the Federal Aviation Regulations (FARs). Hence, first-generation RLV enterprises would do well to design and manufacture their flight vehicles with an eye toward eventually complying (at some level) with the appropriate FAR standards.[65]

The first case involving liability of an aerospace manufacturer for a defective product malfunctioning in space, *Appalachian Insurance Co v. McDonnell Douglas Corp.*, was filed in California state court in January 1996.[66] In this case, the insurer ultimately sought damages based on the negligence of three manufacturers in designing, manufacturing, and testing the PAM-D, a payload assist module, and its STAR 48 solid rocket motor (SRM) and new carbon-carbon involute exit cone. Damages were also sought from the manufacturers for negligently failing to warn SRM users of defects in the STAR 48's exit cone.[67]

Strict Liability

A significant problem presented by the prospect of property damage and personal injury caused by a negligently constructed aircraft has been the difficulty of proof—causing a shift towards the theory of strict liability.[68] The decision that gave birth to this doctrine in aviation product liability law was *Greenman v. Yuba Power Products* in 1963,

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[62] Fobe, Aviation 87.

[63] Fobe, Aviation 87.

[64] Fobe, Aviation 87.

[65] Of particular importance are FAR Part 21, *Certification Procedures for Products and Parts*; and Part 25, *Airworthiness Standards: Transport Category Airplanes*. The "conceptual" application of these standards to RLVs will be discussed in the section entitled, "Deriving an Acceptable Level of RLV Space-worthiness."

[66] Bostwick, Liability 77.

[67] Bostwick, Liability 85.

[68] Fobe, Aviation 88.

where Chief Justice Traynor provided the following opinion on the definition of strict liability:

> A manufacturer is strictly liable in tort when an article he places on the market, knowing that it is to be used without inspection for defects, proves to have a defect that causes injury to a human being.[69]

Strict liability requires that the injured third party only show that the product itself is defective to ensure recovery. For this standard, only three elements need to be proven:[70]

1. the existence of a defect;
2. the defect existed at the time the product left the manufacturer's control; and
3. the defect caused the injury.

Two years following the historic *Greenman v. Yuba Power Products* decision, strict liability was adopted, in amended form, in Section 402A of the Restatement (Second) of Torts. This section provides that:[71]

1. One who sells any product in a defective condition unreasonably dangerous to the user or consumer or to his property is subject to liability for physical harm thereby caused to the ultimate user or consumer, or to his property, if
   (a) the seller is engaged in the business of selling such product, and
   (b) it is expected to and does reach the user or consumer without substantial change in the condition in which it is sold.
2. This rule applies although
   (a) the seller has exercised all possible care in the preparation and sale of his product, and
   (b) the user or consumer has not bought the product from or entered into any contractual relationship with the seller.

In the late 1960's and 1970's the strict liability doctrine had been applied in many aviation product liability cases. For example, in the *Berkebile v. Brantly Helicopter Corp*. decision in 1975, the Pennsylvania Supreme Court stated:

> The crucial difference between strict liability and negligence is that the existence of due care, whether on the part of the seller or consumer is irrelevant. The seller is responsible for injury caused by his defective product even if he has exercised all possible care in the preparation and sale of his product.[72]

However, the doctrine of strict liability may not be considered applicable in all product liability cases.

In ***Wangeman v. General Dynamics Corp.,*** General Dynamics was sued for the wrongful death of a test pilot who lost his life in an airplane crash.[73] Although the

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[69] Fobe, Aviation 88.

[70] Fobe, Aviation 88.

[71] Fobe, Aviation 89.

[72] Fobe, Aviation 89.

[73] Randall R. Craft, Jr., "Manufacturers' Liability Under United States Law for Products Used in Commercial Space Activities," *14 Journal of Space Law* (University, Mississippi: University of Mississippi Law Center, 1986) 131.

plaintiff argued that General Dynamics should be held liable under strict liability, this doctrine was found to be inappropriate because the aircraft in question was an unfinished pre-production prototype in the process of being tested and evaluated by a subcontractor.[74] By similarity, some first-generation reusable launch vehicles could be considered experimental (if not one-of-a-kind) products that are not being commercially distributed—hence, manufacturers of these RLVs may not be subject to strict liability.

RLV Indemnification Considerations

Insuring reusable launch vehicle risks will present unique challenges that are materially different from those of aircraft. For example, aircraft insurers are able to assess their risks, and charge premiums:[75]

- based on historical data showing few losses;
- placed on thousands of identical aircraft sold and operated around the world;
- relying on proven technology which is not subject to extraordinary forces;
- taking advantage of long accepted risk management techniques including limitations of liability in the Warsaw and related conventions; and
- acting on voluminous and meaningful readily accessible information.

Needless to say, none of these factors will apply to first generation RLVs. In fact, first generation RLV insurers will have nothing but the dismal reliability record of the expendable launch vehicle industry to rely upon. With failure rates averaging 16.0% between 1992-1994 and 14.8% between 1993-1995,[76] RLV risks will: "…present a series of…problems, such as critically low predictability, almost complete lack of risk spreading through homogeneous units, technological volatility, inability to exercise meaningful risk control and containment, and the nearly absolute asymmetry of information."[77]

Space insurance has historically provided asset-based coverage for satellites, and replacement launch services coverage for expendable launch vehicles in the event of loss, damage or malfunction.[78] In addition, third party liability coverage is also available for the launch and deployment phases of a launch vehicle's operation. This liability coverage is a legal requirement under the domestic laws (or licensing practice) of the launching state, which in turn are subordinated to international space treaties.[79] Typical insurance

[74] Craft, Jr., Manufacturers' 131.

[75] Bender, Space Transport 250.

[76] Richard Gimblett, "Space Insurance into the Next Millenium," *Outlook on Space Law Over the Next 30 Years*, eds. G. Lafferranderie and D. Crowther (The Hague: Kluwer Law International, 1997) 168.

[77] Bender, Space Transport 250.

[78] Gimblett, Space Insurance 163.

[79] These treaties include: the Convention on International Liability for Damage Caused by Space Objects ("Liability Convention"), March 29, 1972; and the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies ("Outer Space Treaty"), October 10, 1967.

premiums covering a launch vehicle's asset value currently vary between 14% and 25% of the value insured; whereas, third party liability coverage rates run in the range of 0.1% of the applicable policy limit.[80]

In order to mitigate first generation RLV-unique risks, insurers will rely on the historical practice of providing indemnity for a multi-phase ELV operation. However, four separate phases of operation will need to be considered in the case of RLVs:[81]

1. pre-launch, which will cover the RLV during integration procedures, testing and all other stages of launch site operations prior to launch;
2. launch cover, which generally begins at launch ignition and lasts through the orbit attainment phase of the RLV system;
3. in-orbit cover, which will begin simultaneously with the termination of the launch cover, and is relevant to the on-orbit operation of an RLV system; and
4. re-entry cover, which will begin at retrograde ignition (de-orbit burn) and end with recovery of the RLV system on the ground.

Within the boundaries of these operational phases, assessing the risk for first generation reusable launch vehicles will focus on the type of products (e.g., subsystems, components, etc.) comprising the RLV system and the inherent dangers associated with them.[82] In addition, insurers will take into account the RLV system manufacturing process; system ground and flight-testing, and flight vehicle insurable performance parameters (e.g., the flight vehicle's ability to deliver a payload at the correct state-vector) for each mission.

Financial responsibility and allocation of risk requirements for commercial RLV space launch activities authorized under an AST launch license are contained in 14 CFR Part 440. These requirements include:

- Sec. 440.7, Determination of maximum probable loss (MPL);[83]
- Sec. 440.9, Insurance requirements for licensed launch activities;[84, 85]

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[80] Gimblett, Space Insurance 164-165. **Note:** Third party liability coverage rates are relatively low because expendable launch vehicle flight trajectories are typically over the ocean. Hence, the loss experience and *perception* is low.

[81] Gimblett, Space Insurance 164.

[82] Fobe, Aviation 129.

[83] Sec 440.7 (a) states: "The [AST] shall determine the maximum probable loss (MPL) from covered claims by a third party for bodily injury or property damage, and the United States, its agencies, and its contractors and subcontractors for covered property damage or loss, resulting from licensed launch activities. The maximum probable loss determination forms the basis for financial responsibility requirements issued in a license order."

[84] Sec 440.9 (c) states: "The [AST] shall prescribe for each licensee the amount of insurance required to compensate the total of covered third-party claims for bodily injury or property damage resulting from licensed launch activities in connection with any particular launch. The amount of insurance required is based upon the [AST's] determination of maximum probable loss; however, it will not exceed the lesser of: (1) $500M; or (2) the maximum liability insurance available on the world market at a reasonable cost, as determined by [AST]."

- Sec. 440.17, Reciprocal waiver of claims requirements;[86] and
- Sec. 440.19, United States payment of excess third-party liability claims.[87]

In addition, major legislation pending in the Senate (S.1250, Sec. 317) authorizes the NASA Administrator to provide liability insurance and indemnification to developers of Government-sponsored experimental aerospace vehicles—subject to specified conditions and limitations.

Based on the foregoing, it is obvious that the space indemnity market (through less risk, and lower insurance rates) would benefit immensely from the international certification of RLV space-worthiness standards, comparable to those existing in aviation since the Chicago Convention of 1944.[88, 89]

Deriving an Acceptable Level of RLV Space-worthiness

A key principle of systems engineering in the commercial reusable launch vehicle industry is that an RLV design should be considered holistically, and not as the mere sum of its parts. Another principle is that the design criteria for an RLV and its subsystems should emanate from a logical set of performance requirements and operability attributes, and comply (at some level) with an appropriate set of standards for certification. These standards then, should form the basis against which the system will be flight-tested.

First-generation reusable launch vehicles then, will become catalysts for the codification of RLV-specific space-worthiness standards—their potential to evolve into

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[85] Sec 440.9 (e) states: "The [AST] shall prescribe for each licensee the amount of insurance required to compensate [claims by the United States, its agencies, and its contractors and subcontractors involved in licensed launch activities for property damage or loss] resulting from licensed launch activities in connection with any particular launch. The amount of insurance required is based upon a determination of maximum probable loss; however, it will not exceed the lesser of: (1) $100M; or (2) the maximum liability insurance available on the world market at a reasonable cost, as determined by [AST]."

[86] Sec 440.17 (b) states: "The licensee shall implement reciprocal waivers of claims with its contractors and subcontractors, its customer(s) and the customer's contractors and subcontractors, under which each party waives and releases claims against the other parties to the waivers and agrees to assume financial responsibility for property damage it sustains and for bodily injury or property damage sustained by its own employees, and to hold harmless and indemnify each other from bodily injury or property damage sustained by its employees, resulting from licensed launch activities, regardless of fault."

[87] Sec 440.19 (a) states: "The United States pays successful covered claims (including reasonable expenses of litigation or settlement) of a third party against the licensee, the customer, and the contractors and subcontractors of the licensee and the customer, and the employees of each involved in licensed launch activities to the extent provided in an appropriation law or other legislative authority providing for payment of claims in accordance with 49 U.S.C. 70113, and to the extent the total amount of such covered claims arising out of any particular launch: (1) exceeds the amount of insurance required under Sec. 440.9 (b); and (2) is not more than $1.5B (as adjusted for inflation occurring after January 1, 1989) above that amount."

[88] Gimblett, Space Insurance 168.

[89] The Convention on International Civil Aviation (signed at Chicago, on 7 December 1944), Chapter VI, Article 37, states: "…To this end the International Civil Aviation Organization shall adopt and amend from time to time, as may be necessary, international standards and recommended practices and procedures dealing with:…(e) Airworthiness of aircraft…"

globe spanning space transportation systems operating on a daily basis is immeasurable. It is only logical that these operationally prevalent RLVs will be expected to function within the confines of an international regulatory framework, and an established airworthiness code as provided by Annex 8 to the Convention on International Civil Aviation.[90] It should be noted, in one author's view, that "any proposal for a future legal regime will naturally use this body of law as its starting point."[91]

The Role of the Federal Aviation Regulations

Regulations and minimum standards relating to the manufacture, operation and maintenance of aircraft are resident in Title 14 of the U.S. Code of Federal Regulations, Chapter I, Parts 1 through 199 (14 CFR, Chapter I). These regulations and standards have their legacy in the Air Commerce Act of May 20, 1926, as amended by the Federal Aviation Act of 1958, and Public Law 103-272 in 1994[92]—and have evolved considerably since the introduction of jet airliners. In fact, the Air Commerce Act "was passed at the urging of the aviation industry, whose leaders believed the airplane could not reach its full potential without Federal action to improve and maintain safety standards."[93] Likewise, it is in the reusable launch vehicle industry's best interests to pursue a similar paradigm.

As previously mentioned, the Federal Aviation Regulations (FARs) have evolved since their inception to accommodate the introduction of new aviation technologies—and are inherently flexible enough to address RLV-unique attributes. This is evident in FAR Part 1, Sec. 1.1, which defines the certification of aircraft by *Category*, *Class* and *Type*. Specifically:

- "Category:" …(2) As used with respect to the certification of aircraft, means a grouping of aircraft based upon intended use or operating limitations. Examples include transport, normal, utility, acrobatic, limited, restricted, and provisional.
- "Class:" …(2) As used with respect to the certification of aircraft, means a broad grouping of aircraft having similar characteristics of propulsion, flight, or landing. Examples include airplane; rotorcraft; glider; balloon; land-plane and seaplane.
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[90] The constitution of the International Civil Aviation Organization (ICAO) is the *Convention on International Civil Aviation*, drawn up by a conference in Chicago in November and December 1944, and to which each ICAO Contracting State is a party. **Source:** "Facts About ICAO," *International Civil Aviation Organization Homepage* (Online.@ http://www.icao.int/cgi/goto.pl?icao/en/download.htm).

[91] Stockfish, Space 331.

[92] "About the FAA," *Federal Aviation Administration Homepage* (Online @ http://www.faa.gov/about.htm).

[93] "About the FAA," Federal.

- "Type:" …(2) As used with respect to the certification of aircraft, means those aircraft, which are similar in design. Examples include: DC-7 and DC-7C; 1049G and 1049H; and F-27 and F-27F…(3) As used with respect to the certification of aircraft engines means those engines which are similar in design. For example, JY8D and JT8D-7 are engines of the same type, and JT9D-3A and JT9D-7 are engines of the same type.

Furthermore, Section 1.1 defines "Rocket" as "an aircraft propelled by ejected expanding gases generated in the engine from self-contained propellants and not dependent on the intake of outside substances. It includes any part which becomes separated during the operation." This definition, in combination with the definition for "Powered-lift,"[94] will readily allow reusable launch vehicles—differentiated by category, class, and type—to be included in the FAR aircraft certification process.

In the lexicon of the FARs, *airworthy* is defined as "an aircraft that meets its type design and is in a condition for safe operation."[95] By similarity then, a reusable launch vehicle will be considered *space-worthy* if it also meets these requirements. Hence, by following the same process and standards aircraft use to acquire a type certificate, RLVs can qualify for a *standard space-worthiness certificate*—which is the equivalent of an aircraft *standard airworthiness certificate.* The legal basis for this can be found in FAR Part 21, Section 21.17(b):

> For special classes of aircraft, including the engines and propellers installed thereon (e.g., gliders, airships, and other non-conventional aircraft), for which airworthiness standards have not been issued under this subchapter, the applicable requirements will be the portions of those other airworthiness requirements contained in Parts 23, 25, 27, 29, 31, 33, and 35 found by the Administrator to be appropriate for the aircraft and applicable to a specific type design, or such airworthiness criteria as the Administrator may find provides an equivalent level of safety to those parts.[96]

Likewise, an applicant is entitled to a type certificate for a reusable launch vehicle if, in accordance with FAR Part 21, Section 21.21(b):

> The applicant submits the type design, test reports, and computations necessary to show that the product to be certificated meets the applicable airworthiness, aircraft noise, fuel venting, and exhaust emission requirements of the Federal Aviation Regulations and any special conditions prescribed by the Administrator…

Like its aircraft counterpart, a reusable launch vehicle's space-worthiness certificate would be effective as long as the maintenance, preventive maintenance, and alterations

[94] "'Powered-lift' means a heavier-than-air aircraft capable of vertical takeoff, vertical landing, and low speed flight that depends principally on engine-driven lift devices or engine thrust for lift during these flight regimes and on non-rotating airfoil(s) for lift during horizontal flight."

[95] This definition is taken from Public Law 103-272, previously the Federal Aviation Act of 1958, and is also found on the face of each aircraft's standard airworthiness certificate.

[96] Part 23–Airworthiness Standards: Normal, Utility, Acrobatic, and Commuter Category Airplanes; Part 25–Airworthiness Standards: Transport Category Airplanes; Part 27–Airworthiness Standards: Normal Category Rotorcraft; Part 29–Airworthiness Standards: Transport Category Rotorcraft; Part 31–Airworthiness Standards: Manned Free Balloons; Part 33–Airworthiness Standards: Aircraft Engines; Part 35–Airworthiness Standards: Propellers.

were performed in accordance with Parts 21, 43, and 91 of the Federal Aviation Regulations, as appropriate, and the RLV was registered in the United States.[97]

The Role of Flight Testing

Flight-testing will be a critical precursor to the successful introduction of commercial reusable launch vehicle flight operations. In addition to validating the requisite performance and operational capabilities of commercial RLVs—including safety compliance—first generation systems will establish the precedent for successfully operating in the present-day air and space legal regimes.

Flight-testing of first-generation reusable launch vehicles is readily accommodated in the appropriate subsections of FAR Part 21, Section 21.191, which state:

> Experimental certificates are issued for the following purposes:
> (a) Research and development. Testing new aircraft design concepts, new aircraft equipment, new aircraft installations, new aircraft operating techniques, or new uses for aircraft.
> (b) Showing compliance with regulations. Conducting flight tests and other operations to show compliance for issuance of type and supplemental type certificates, flights to substantiate major design changes, and flights to show compliance with the function and reliability requirements of the regulations…

First-generation reusable launch vehicles will operate under experimental certificates until compliance with their type certificate requirements is proven. In addition, the collection of time-age-cycle data on critical RLV subsystems and structures will be instrumental in the derivation of RLV-unique, space-worthiness standards.

The Effect of RLV Space-worthiness Standards on Indemnification

The international regulation of RLV space-worthiness standards will favor the space indemnity market with significantly lower insurance rates by improving the commercial viability and *safety* of reusable launch vehicles, as manifested in three fundamental areas: reusability, reliability and quality control.

Reusability

Reusability will have a positive impact on the space insurance market as RLVs become more ubiquitous over the next 30 years. Within this time span, reusable launch vehicles will begin to have more in common with traditional aviation transport systems than with their progenitors—the expendable and partially reusable launch systems (i.e., Space Shuttle) in use today. For example, the ELV paradigm of insuring the cost of a replacement launch[98] will give way to insuring the asset value of the entire RLV system itself. In essence, the cost of insuring the reusable launch vehicle system will now be

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[97] From "Terms and Conditions" found on the face of a Standard Airworthiness Certificate. Also, Part 21–Certification Procedures for Products and FAR Parts; Part 43–Maintenance, Preventive Maintenance, Rebuilding, and Alteration; Part 91–General Operating and Flight Rules.

[98] The replacement cost of an expendable launch vehicle includes the costs associated with: replacing flight vehicle hardware and software; launch vehicle integration and processing; payload integration; propellants; and range services.

amortized over the operational life of the system, thus significantly reducing the *per mission* insurance rates.

Reusability also implies quick turnaround on the ground and significantly reduced end-to-end mission timelines. Hence, the initial four–phase approach for insuring a reusable launch vehicle mission (previously outlined) can now be consolidated into a separate ground phase and flight phase—which is more in line with the functional approach for assessing an RLV's susceptibility to risk. This consolidation down to two separate operations phases will drive insurance rates down even further.

Reliability

Another factor that will have a critical influence on the insurability of reusable launch vehicles will be the reliability of RLV subsystems. High reliability rates for robust subsystems can only be achieved by incorporating the factors of safety and levels of redundancy necessary to sustain reusability levels that are commercially viable. These attributes, in combination with a Reliability Centered Maintenance (RCM) methodology and quality control regimen, will contribute greatly to lowering operations and insurance costs.

Reliability Centered Maintenance originated in the commercial aviation industry in the late 1960's,[99] and will use a structured methodology for establishing RLV subsystem maintenance requirements based on the consequences of failure. The collection of time-age-cycle data for each subsystem (via an integrated vehicle health monitoring and reporting subsystem) will be crucial to the success of this RCM process during the developmental phase of first generation RLV systems. And from a long-term perspective, assessments of RLV insurability will also depend upon the proper collection and analysis of the time-age-cycle data.[100] Hence, the RCM methodology is designed to maintain high levels of system reliability and availability, although the implementation of an effective RCM process is only one variable in the equation for high reliability. The other variable in this equation is quality control in the design and fabrication of RLV subsystems.

Quality Control

The reliability of a reusable launch vehicle system will, to a large extent, depend upon the quality of the individual subsystems that comprise the flight vehicle and ground system.[101] It is incumbent upon the RLV enterprise, therefore, to "…maintain a system for the management of quality which includes planning, control, inspection, and assurance activities—each appropriate to the product [or subsystem] being offered. The

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[99] "Common Questions About RCM," *International Reliability Consultants Homepage* (Online @ http://www.ircrcm.com/quest.htm).

[100] For each mission, over a 5 year time period. In the evaluation of past claims records, insurers usually require claims experience over the last five years in terms of number and cost. **Source:** Fobe, Aviation 129.

[101] Assuming, of course, that the flight vehicle can still achieve its performance objectives after incorporating all of the requirements mandated by a well executed quality assurance program.

principles of quality management as well as the quality system elements are laid down in national and international standards, such as EN 29000 and ISO 9000."[102]

The international regulation of RLV space-worthiness standards would ensure that prime contractors and subcontractors implemented the necessary measures for managing risk and preventing failures in reusable launch vehicle subsystems. However, mere adherence to these standards may not be enough, because they would represent the "minimum" requirements for mitigating liability. The key to reliable, reusable launch vehicles is the robust subsystems capable of withstanding the rigors of reuse in the air and space environments, with minimal maintenance and downtime—this implies a duty of care requiring the strict implementation of quality control principles.

Conclusion

The reusable launch vehicle industry, as a whole, has failed to acknowledge the underlying theme of liability that is inherent in space launch vehicles designed to be operated and maintained like traditional high performance, heavy jet aircraft. This paper has examined the factors contributing to an RLV's exposure to liability, which include performance shortfalls, high usage rates, fast turnaround times with minimum maintenance, and operational over-flight corridors. Liability principles inherent in domestic and international space law were then discussed, followed by an examination of the liability doctrines relevant to reusable launch vehicle space-worthiness. Finally, a method for certifying an RLV's space-worthiness was introduced that is conceptually patterned after the FAA standards used to certify aircraft airworthiness. As flight-testing of first-generation reusable launch vehicles continues, these systems will become catalysts for the eventual codification of RLV-specific space-worthiness standards

In conjunction with a systems engineering approach in the reusable launch vehicle certification process, space-worthiness standards will serve to synthesize and validate next-generation RLV designs that are higher in quality, meet required performance objectives, and are economically maintainable. These attributes, in turn, will mitigate the liability risks inherent in the *ultra-hazardous*[103] operation of these systems—and better provide for the public safety.

[102] Mariagrazia Spada, "Quality Control in Production of Space Objects and Liability in Outer Space Law," *Outlook on Space Law Over the Next 30 Years*, eds. G. Lafferranderie and D. Crowther (The Hague: Kluwer Law International, 1997) 193.

[103] As defined by the Courts.

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3.0 ELEMENTS OF RLV REGULATORY REGIME

3.1 Elements of a Licensing Regime (submitted by Kistler Aerospace)

The proper development of a licensing regime for RLVs requires an understanding of the industry's characteristics - how it is similar to and how it is different from other industries. Among the relevant characteristics are the following:

- RLV Industry Development Is Taking Place in a Commercial Environment
  Unlike the Expendable Launch Vehicle industry which was conceived and brought to maturity using Government funding under Government direction, the RLV industry is operating in a commercial venue from its inception.

  Consequently, to foster an RLV industry, any regulatory regime must provide two things:
  i. Certainty - to ensure investors that while regulatory approval is required, the process is clear and navigable
  ii. Flexibility - to ensure investors that all concepts are addressable in an unbiased and expeditious manner by the regulatory authority.

- The RLV Industry is in its Infancy
  As with any nascent industry, a poorly thought out regulatory environment could easily lead to an industry wide infanticide. It is worth noting here the timeline by which the aviation industry came under regulation.

  The Wright brothers' first flight occurred in December 1903 at Kitty Hawk, North Carolina. It was not until 1926, however, that the Aeronautical Branch of the Department of Commerce, the predecessor to the FAA, was formed. By that time barnstorming, mail flights, and other irregularly scheduled aviation activities were widespread. The Aeronautical Branch certified its first airplane in 1927, twenty-four years after the Wright brothers' first flight.

  The Aeronautical Branch became the Federal Aviation Administration in 1958 with the passage of the Federal Aviation Act, but it was not until 1965 that FAR 25, the primary standard for commercial aircraft design, was issued. In other words, it was not until 1965 that enough standardization had occurred among the dozens of aircraft developers that a single document could serve as minimum design requirements to all developers without bias.

  Even could it have been written, the issuance of FAR 25 in 1902 would have spelled the end of the aviation industry before it was born. Such a regulatory regime is built upon historical precedent and presupposes a standardization of design concepts and operational scenarios not realizable in an infant industry.

In the RLV industry, while the technology and hardware are generally well understood, the configurations into which they are assembled - the design concepts and operational scenarios - are far from standardized. Consequently, *any RLV licensing regime must be developed without pre-supposing a particular design concept or operational scenario*

- The Importance of Vehicle Return

  Unlike ELV operators, the operator of a Reusable Launch Vehicle considers the vehicle itself a company asset. Aside from the technicality that any new licensing regime must now take into account re-entry as well as ascent, this fact has philosophical implications for the development of any new licensing regime.

  Since the vehicle return is critical to the RLVs commercial success, the developer and the operator have likely made significant efforts to design the system and its operations for reliable mission completion. This has proven true in the aviation industry where dispatch reliability and the survival of airline assets largely drive the redundancy levels of the aircraft design, not public safety. Consequently, *any RLV licensing regime should maximize the use of existing developer and operator analyses and documentation, and minimize analyses and documents which serve only a regulatory purpose.*

  It should be noted here that it is more difficult to conduct a mission where the vehicle returns intact and undamaged for future flights than it is to conduct a mission without causing any casualties among the general public. There are in fact multitudes of places where a vehicle can land, even crash, without harming anyone, but still sustain enough damage to be unusable by the operator. Consequently, mission completion in many ways is a "stricter standard" for safety, and any prudent action taken by a system's developer to promote confidence in vehicle return more than serves the public safety interest being guarded by the FAA.

  In summary then, a licensing regime for RLVs:

  1. Must provide certainty and flexibility to the industry being regulated;
  2. Must be developed without pre-supposing a particular design concept or operational scenario;
  3. Should maximize the use of existing developer and operator analyses and documentation, and minimize analyses and documents that serve only a regulatory purpose.

3.1a Documentation Requirements

Since the full development of an RLV licensing regime requires the attention and consideration of many minds, it is not possible here to present a definitive licensing regime. Instead, an approach to generating such a licensing regime is presented along with an illustrative listing of documents that could serve as licensing submittals. *The final licensing regime recommendation will consist of a set of documents that industry and regulators feel represent a* <u>*necessary and sufficient*</u> *submittal for the FAA to do its job.*

The purpose of an RLV licensing regime is to make certain that the safety of the general public is considered in the operation of any such system. The development of an RLV licensing regime, then, begins with the regulators' fundamental question, "Is it safe?"

This question is too broad to answer directly, but it can be used to initiate a cascade of questions (Figure 1) to which definable analyses and documents can provide answers. That list of analyses and documents then becomes the required set of submittals for licensing purposes.

As currently envisioned, there are four second tier questions that must be answered for licensing.

1.) What is "it?"
2.) Is it designed to be safe?
3.) Is it built as designed?
4.) Is it operated safely?

1. What is "it?"

   As a condition of licensing, it is required that the license holder inform the FAA of any substantive changes to the design and operation of a system. Consequently it is necessary to establish as part of the licensing process the formal definition of the system being licensed. Such a definition could include top level specifications and drawings, a weight and balance statement, and the identification of materials.

   The depth of this baseline definition must be agreed to. Clearly the removal and replacement of interchangeable parts - parts with the same part number but different serial numbers - should not be considered a design change. However, more ambiguous level of definition questions will need to be resolved.

2. Is it designed to be safe?

   Vehicle design is a primary contributor to system safety. However, analyses conducted by the developer to ensure the intact return of the vehicle should serve well in an assessment of design safety. Efforts such as a Failure Modes, Effects, and Criticality Analyses (FMECA),

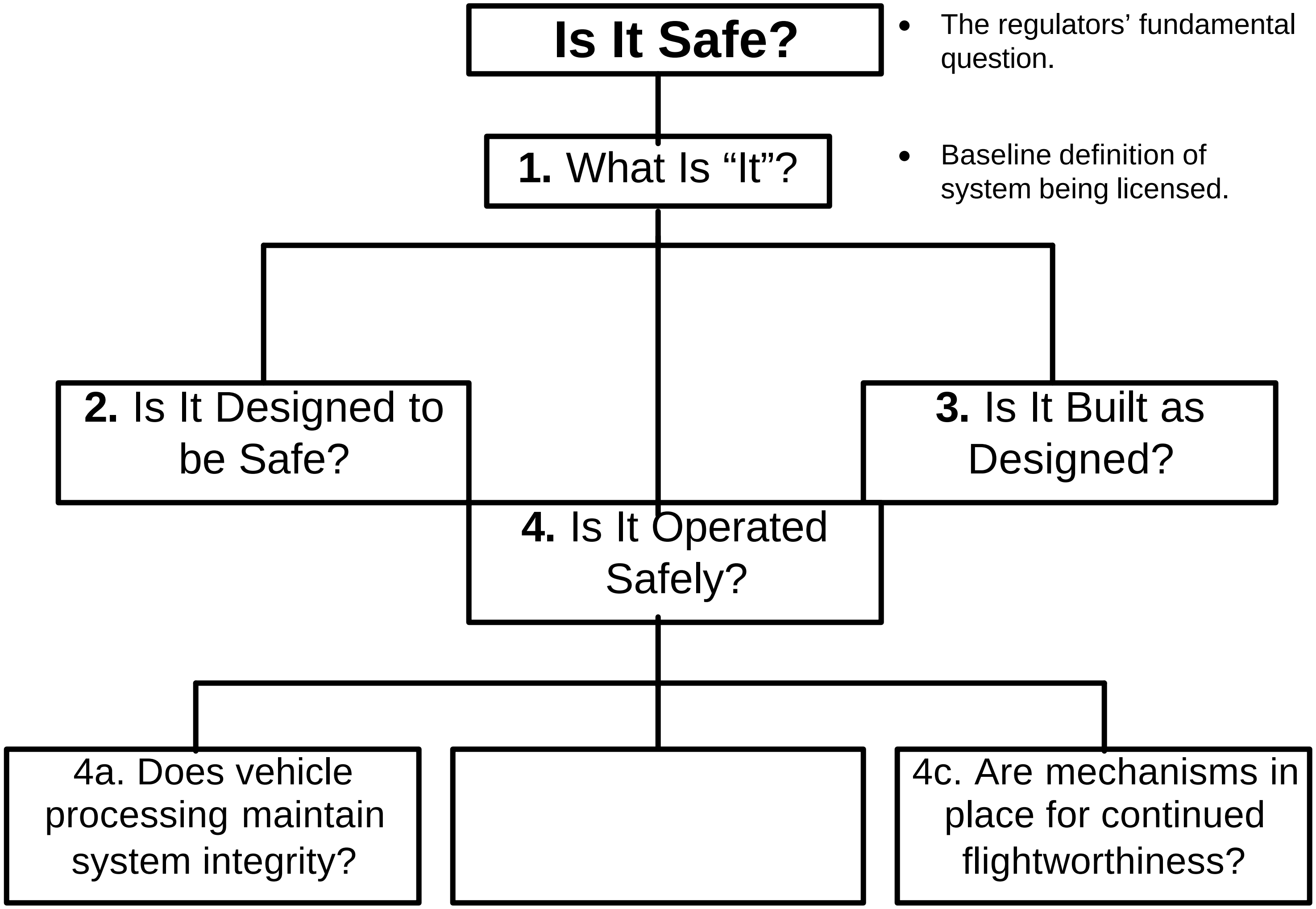

Figure 1 - A Cascade of Questions

Sneak Circuit Analyses (SCA), and component test reports would serve well as licensing submittals in support of a design safety assessment.

3. Is it built as designed?
With a satisfactory answer to the question of system design safety, the question arises as to whether or not the vehicle "as built" is in conformance with the vehicle "as designed." Once again, the developer's own efforts to increase the likelihood of intact recovery should serve well to provide assurance that the vehicle and its components were built as designed.

   Presentation of a Quality Assurance Plan and subsequent reports from the quality organization provide preliminary confidence that the vehicle is in conformance. Highly integrated tests such as Hardware-in-the-Loop (HWIL) tests would confirm that the vehicle was integrated as planned and that the software was developed as intended.

   In any event, industry techniques are well known for ensuring a "built-as-designed" product. These techniques and associated reports should also serve as licensing submittals.

4. Is it operated safely?
The last of the second tier questions concerns the operation of the system. System operations safety depends upon three lower level activities 1) between flight maintenance and processing (Does vehicle processing maintain system integrity?), 2) range operations (Are mechanisms in place for safe flight?), and 3) inspection activities (Are mechanisms in place for continued flightworthiness?)

   Once again, these regulatory questions could be addressed with documents created by the developer and/or the operator in seeking the intact return of the vehicle after each flight.

   - <u>Does vehicle processing maintain system integrity?</u>
     In general, both the operator and the FAA will want to be sure that between flight maintenance does not introduce faults into the system. There are many ways to address this concern. The simplest may be to acquire concurrence from the FAA that the pre-flight test and checkout procedures developed by the operator are sufficiently inclusive to detect any processing induced fault.

   - <u>Are mechanisms in place for safe flight?</u>
     Operators will be required to have management and communication mechanisms in place to address range related

issues. Among them may be airspace coordination, NORAD notification, road closures where applicable, etc.

- Are mechanisms in place for continued flight-worthiness?
  Continued flightworthiness is a matter of conducting regular inspections of non-serviceable components (primarily structure), and learning lessons from any accidents that do occur.
  There are many well-established methods for choosing inspection intervals of flight hardware, and the presentation of the operator's Critical Component List (CCL) and CCL Management Plan would serve well as the foundation of a continued flightworthiness program.
  In regard to accidents, major or minor, the operator should have a plan and procedures in place to respond to an accident in such a way that the cause of the accident can be determined and corrections can be made. An Accident Response Plan should serve this purpose.

Organizationally this cascade of questions relates easily to program phases. Question 2, "Is it designed to be safe?" corresponds to the design and development phase of a program. Questions 3, "Is it built as designed?" corresponds to the manufacture and assembly phase of the program, and question 4, "Is it operated safely?" corresponds to the operational phase of the program.

Table 1 summarizes a hypothetical list of documents that might comprise a licensing submittal for an RLV and identifies the program phase to which each relates.

3.1b Assessment Guidelines and Role of AST Licensing Supervision

The question now arises as to how these submittals should be assessed by the licensing agency. The aviation certification process is not applicable here.

The commercial aircraft certification process confirms system compliance with a set of detailed design and manufacturing standards. For the aviation industry, those standards have been developed over the past 70 years as a direct product of operational experience. As mentioned earlier, FAR 25, the primary source for commercial aircraft design standards was not published until 1965 when the industry had gained sufficient operational experience and aircraft design had become relatively standardized. The RLV industry cannot boast either of these features and consequently there is no possible set of standards to which all developers must comply

Table 1 – Hypothetical List of RLV Licensing Submittals

	Is It Designed to be Safe? (Design & Development Phase)	Is It Built As Designed? (Manufacture & Assembly Phase)	Is It Operated Safely? (Operations Phase)
• Program Management Plan	X	X	X
• System Specifications	X	X	X
• System Engineering and Integration Plan	X	X	X
• Master Verification Test Plans and Results		X	
• FMECA	X		
• Critical Components List and Management Plan		X	X
• Flight Test Program Plan		X	
• Launch Operations Plan			X
• System Safety & Health Plan		X	X
• Quality Assurance Plan			X
• Contingency & Emergency Management Preparedness Plan			X
• Maintenance Plan			X
• Hazard Analysis			X

Furthermore, there is no reason to believe that any arbitrary set of standards developed would in any way result in safer systems.

As with any new industry being brought under regulation, regulatory assessment will rely upon engineering judgment and the development of confidence in the underlying processes rather than simply checking for compliance to a set of numerical values. It will be incumbent upon developers and regulators to shape a relationship that allows for the communication of the integrity of the design, manufacturing and operational processes at the heart of creating a safe system.

In assessing the adequacy of a system for licensing, the FAA should rely upon the various industry standards available, including, but not limited to:

- Society or Automotive Engineers (SAE) Aerospace Standards
- International Organization for Standardization (ISO) standards
- Military Standards

These standards represent a foundation for FAA assessment of new systems. Where individual developers diverged from a given standard, it is the FAA's responsibility to understand the reasons for that divergence and the process that led to the alternate design. In this manner, innovative solutions to design and operational problems are encouraged while public safety is guarded.

For this process to be successful, developers and operators must include, in their programmatic planning, tasks that cultivate FAA knowledge and understanding of the system's characteristics, and the processes that led to its creation.

The FAA for its part must employ the expertise necessary to comprehend the idiosyncratic technical processes and decisions at each developer, and interact with each developer's technical staff.

3.2 Elements of a Certification Regime

<u>(To be supplied)</u>

3.3 Role of Casualty Expectation Analysis (submitted by Kistler Aerospace)

The Working Group continues to discuss the role and validity of a casualty expectation analysis for Reusable Launch Vehicles. The group agrees on the following items:

1. Casualty expectation analysis is an art, not a science.
2. As with any other risk analysis that must be based on a small historical sample, the probabilistic nature of the analysis leaves significant room for the imposition of subjective assumptions.
3. History shows that the theoretical system failure probability used as part of a casualty expectation analysis is not related to the actual system failure probability, especially for new systems.

The Working group further notes that the only other industry using a similar methodology is the nuclear power industry, which also conducts such analysis as part of its licensing process under Federal Government oversight.

Opinions currently diverge at this point. Details of the divergent opinions appear below. In general, some Working Group members contend that for all its weaknesses, there is no alternative to a casualty expectation analysis to provide a definitive, quantitative assessment of the hazard posed by a launch system to the general public. This means of assessing safety has contributed to the launch of over 1100 vehicles from the national ranges without incurring a casualty among the general public.

Other Working Group members contend that, aside from the inherent weaknesses of the methodology, the use of a casualty expectation analysis for RLVs is inappropriate for the following reasons:

1. It fails to take into account the effects of between-flight maintenance on the system failure probability.
2. The incorporation of abort modes results in a more complicated and burdensome analysis than that conducted for ELVs, and, due to the need to incorporate more assumptions, it is likely to be even further removed from the actual level of risk presented.

The Working Group intends to continue discussion of this topic and present a final recommendation to the FAA in the future.

3.3a Arguments in Support of Casualty Expectation Analysis (submitted by Lockheed Martin)

The casualty expectation Ec is a direct quantitative measure of the collective risk to the public of launch vehicle operations. As a quantitative measure of public risk it provides public authorities and launch services providers an objective standard to determine the risk and its consequences. The national ranges and the FAA have used this measure to gauge the risk of current ELV operations since the inception of the commercial launch vehicle industry. The casualty expectation analysis consists of two parts. First the probability of a failure must be established. Then the consequences must be assessed. The probability of failure may be based on historical data, subsystem and component data, analytical predictions or most likely a combination of all three. In order to assess the consequences it is necessary to determine both the final state of the system as a result of each potential failure and the population exposed to risk. The population exposed will be a function of the ground track of the instantaneous impact point and population density it traverses over. It should be noted that the over water launch of current commercial launch vehicles from Florida still requires the instantaneous impact point to traverse inhabited regions of Africa (for low inclination missions) and Europe (for higher inclination missions such as ISS) for which an Ec is calculated. The potential debris field resulting from the vehicle breakup is predicted based on a predicted debris catalogue, the trajectory state, and the winds aloft.

Casualty Expectation Analysis is a Valid Technical Procedure Developed by the National Ranges and Recognized by the FAA, NASA and the DOD

The FAA document Hazard Analysis of Commercial Space Transportation Vol III Risk Analysis explains in detail the current approach to calculating the probability of failure and the estimated risk of casualty for current launch vehicles. The procedure has developed from decades of experience by NASA and the DOD in the operation of the national ranges including both expendable vehicles and partially reusable launch vehicles such as the current space shuttle. It is also recognized by the Range Commanders Council Risk and Lethality Commonality Team which established uniform range risk criteria in document RSG 321-97. In this document it is recognized for use with aeronautical systems and unmanned aircraft as well as missiles and space launch vehicles.

In all cases the existence of some uncertainty in the probability of failure is acknowledged, however the recognition of uncertainty in no way invalidates the procedures. Indeed, the existence of uncertainty and the statistical methods for quantifying and dealing with uncertainty are a basic tool for modern science and technology. Current techniques for estimating the probability of failure for launch vehicles include provision for component and subsystem test data and well as probabilistic design techniques which are equally applicable to RLVs. A successful flight test program will improve the confidence interval for these predictions, but the estimate of failure is far more sophisticated than simply dividing the number of failures by the number of flights. Had the mathematical tools for this approach been more widely available and understood at the start of commercial aviation it is quite possible they would have been incorporated into the current approach to certification of aircraft just as the Range Commanders Council has extended them to the flight test of aeronautical systems.

Extension of Casualty Expectation Analysis to Reusable Systems is Straightforward and Already in Use

As discussed above the Range Commanders Council has already extended the use of casualty expectation to reusable systems. The methodology is in use for existing space shuttle launches, and the X-33 flight test program will use this approach.

Procedures for determining the flight readiness status of a vehicle whether by inspection, instrumentation or a certification approach which validates a part for a given number of flights are a factor in the probability of failure, and may be incorporated into the mathematical estimation of casualty like any other factor in the probability of failure.

The Existence of Abort Options for an RLV poses no More Burden to Developers than the Existing Regulatory Regime for ELVs

Current ELVs must incorporate staging events into their casualty estimation. The existence of abort options introduces no more complexity to the analysis process than does the staging process. Concerns abort options would seem to imply a near infinite number of abort opportunities. Realistically, an unmanned RLV is unlikely to have the autonomous decision making capability to exercise abort options outside of a preplanned set of contingencies. Even for a piloted RLV the energy state and thermal environment of a hypersonic vehicle will not permit the pilot unlimited abort opportunities. It should be straightforward to incorporate all realistic abort options into the analysis.

Casualty Expectation Analysis provides both Regulatory Agencies and Launch System Developers an Objective Standard to Assess the Risk to Public Safety

In the absence of an objective standard for establishing the risk to public safety the launch vehicle developer can never be quite sure when he will have completed safety analysis to the satisfaction of the FAA. The casualty expectation analysis provides a common measure for the developer and the FAA in preparing the necessary documentation for the launch approval process. The consequences of a particular design approach, analysis, component test or flight test approach can be assessed objectively and negotiated as part of the early safety consultation process.

3.3b Arguments Opposed to Casualty Expectation Analysis (Submitted by Kistler Aerospace)

The application of a casualty expectation analysis to RLV licensing is technically unsound, ignores the implications of reusability, poses an undue burden on developers, and yields no relief to regulators.

Casualty Expectation Analysis Is Technically Unsound

An integral part of a casualty expectation analysis is the development of a vehicle level failure probability. To determine the theoretical failure probability, the failure probabilities for lower level components, i.e. components that can in fact be tested a statistically valid number of times, are mathematically combined in a "build up" process that yields a system level failure probability, the assumption being that the system is the sum of its parts.

As a prediction of system performance, *even for Expendable Launch Vehicles*, theoretical reliability values generally overstate the reliability of the system, sometimes by vast amounts.

Table 2 shows success rates for a number of commercially operated expendable launch systems. The theoretical reliabilities for these systems, i.e. the built up failure probability used for Casualty Expectation analyses, are generally considered confidential information and are not included in this table. But it can be assumed that any system with a theoretical reliability less than about 0.90 would have a difficult time being licensed.

The values in Table 2 were derived using flight histories for the selected systems and the information presented in Hazard Analysis of Commercial Space Transportation, p 8-15, Table 8-4 for the 95% confidence level. This same information is presented graphically in Figure 2.

The values were determined based upon the number of consecutive successful launches by that vehicle. Where the number of consecutive successful commercial launches, or the number of total commercial launches, were too small for a value to be approximated, the annotation NA was entered. Values for the Ariane family of ELVs are also included since the European Space Agency uses a similar casualty expectation analysis for launch approvals.

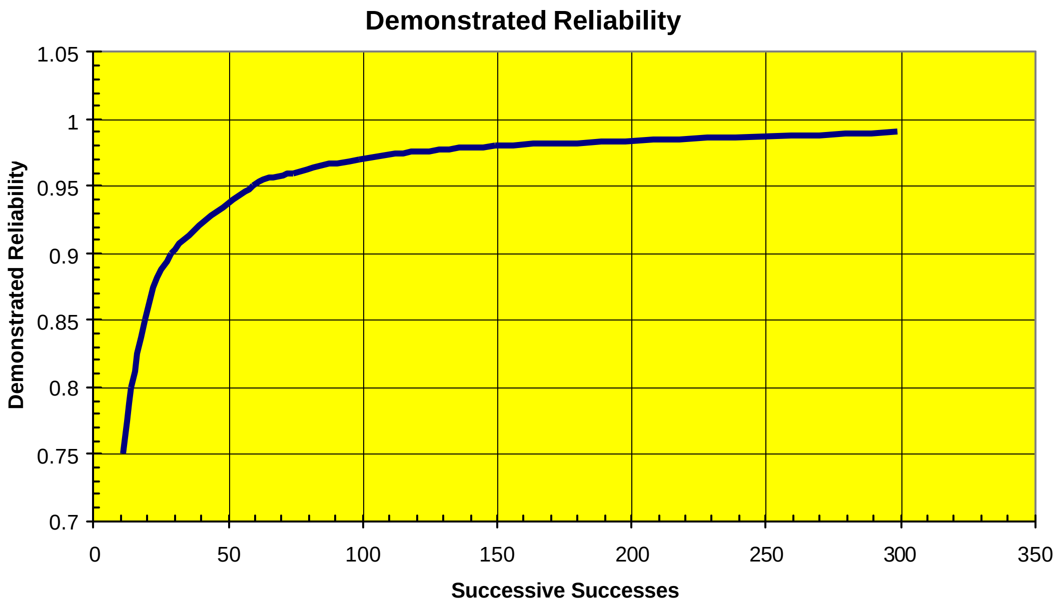

Figure 2 - Number of Tests That Must Be Performed Without Failure to Provide a Specific Minimum Reliability at a 95% Confidence Level

Vehicle	Launch Attempts	Successes	Raw Success Rate	Longest Success String	Demonstrated Reliability (95% confidence)
Commercial Delta since 1980	49	48	**0.98**	45	**0.93**
Commercial Atlas IIAS	9	9	**1.00**	9	**0.70**
Commercial Atlas IIA	10	10	**1.00**	10	**0.74**
Ariane 1	11	9	**0.82**	6	**<0.50**
Ariane 2/3	17	15	**0.88**	10	**0.74**
Ariane 4	77	74	**0.96**	34	**0.91**
Ariane 5	3	2	**0.67**	2	**NA**
Athena	3	2	**0.66**	1	**NA**
Pegasus	9	7	**0.78**	3	**<0.50**
Pegasus XL	13	10	**0.77**	10	**0.74**
Taurus	3	3	**1.00**	3	**<0.50**

Table 2 - Demonstrated Reliabilities for Selected Commercial Launch Systems

As can be seen from Table 2, most expendable systems have demonstrated reliabilities significantly below the assumed value generally considered necessary for licensing purposes.

The reality is that, absent a statistically valid launch history, theoretical failure probability values are subject to significant uncertainty

.

Casualty Expectation Analysis Ignores the Implications of Reusability

The computation of a vehicle level probability of failure for a casualty expectation analysis does not take into account one of the key differences between ELVs and RLVs, that of between-flight maintenance.

RLVs undergo maintenance between flights. Consequently the failure probability for a vehicle's second flight is different from the failure probability for its first flight. (And the third flight is different from the second, and so on.) Technical arguments have been made that reusability causes system reliability to increase, and other arguments have been made that reusability causes system reliability to decrease.

In any event both parties agree that for an RLV, a maintenance program is going to significantly impact the vehicle's failure probability for each succeeding flight.

But the casualty expectation ignores between-flight maintenance in its entirety.

Casualty Expectation Analysis Poses an Undue Burden on Developers

One of the innovations being brought to the launch industry by RLVs is abort capability. While a boon to customers and operators who can now anticipate at least the possibility of getting their property back in the event of a failure during launch, the presence of abort capability significantly complicates the computation of the system failure probability that is so important in the ELV casualty expectation calculation.

ELVs have no abort strategy beyond activating the FTS. A top-level event probability tree reflecting this reality is shown in Figure 3. Should a failure occur that is not covered by redundancy, the mission is a loss. Thus the computation of a mission failure probability, however dubious its relation to reality, is relatively straightforward. This is not the case with RLVs.

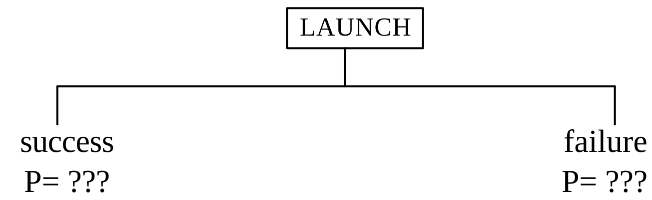

Figure 3 -Top Level Event Probability Tree for a Conventional Expendable Launch Vehicle

Figure 4, a top-level event probability tree for a hypothetical RLV, shows the difficulty encountered in attempting to apply the ELV methodology to RLV licensing. Not only do RLVs have abort capabilities, but also these capabilities vary from system to system. They range from simply targeting a “safe” place to impact, to full Return to Launch Site (RTLS) capability. Even within a given system, the types of failures that can be managed, the strategy to be employed, and the system components necessary to execute the abort vary depending upon the portion of the flight regime where the abort is declared.

All of this leads to a complicated sequence of event gates for each reusable system under design. In addition, because of the multitude of assumptions necessarily incorporated into the analysis, any results will be immediately suspect.

Lack of confidence in the results of a casualty expectation analysis is already apparent in FAA documents. The recently released "Draft Interim Safety Guidance for Reusable Launch Vehicles" requires a casualty expectation analysis in Objective 1. Objective 7, however, implies that over-flight of populated areas will be disallowed regardless of the results of the casualty expectation analysis.

Because of the plethora of conditions needing analysis, and the lack of confidence in the resulting answers, a casualty expectation analysis imposes an undue burden on RLV developers.

Casualty Expectation Analysis Yields No Relief to Regulators

The Casualty Expectation analyses for ELVs are predicated upon the assumption that the Flight Termination System, in most cases a destruct package, would work. It is the presence of a destruct system that allows regulatory authorities to oversee, with relatively little staff, the safety integrity of a relatively complicated system. Knowing the vehicle can be stopped by their command at any time, regulators need not expend resources becoming too conversant in the system’s design. Rather than

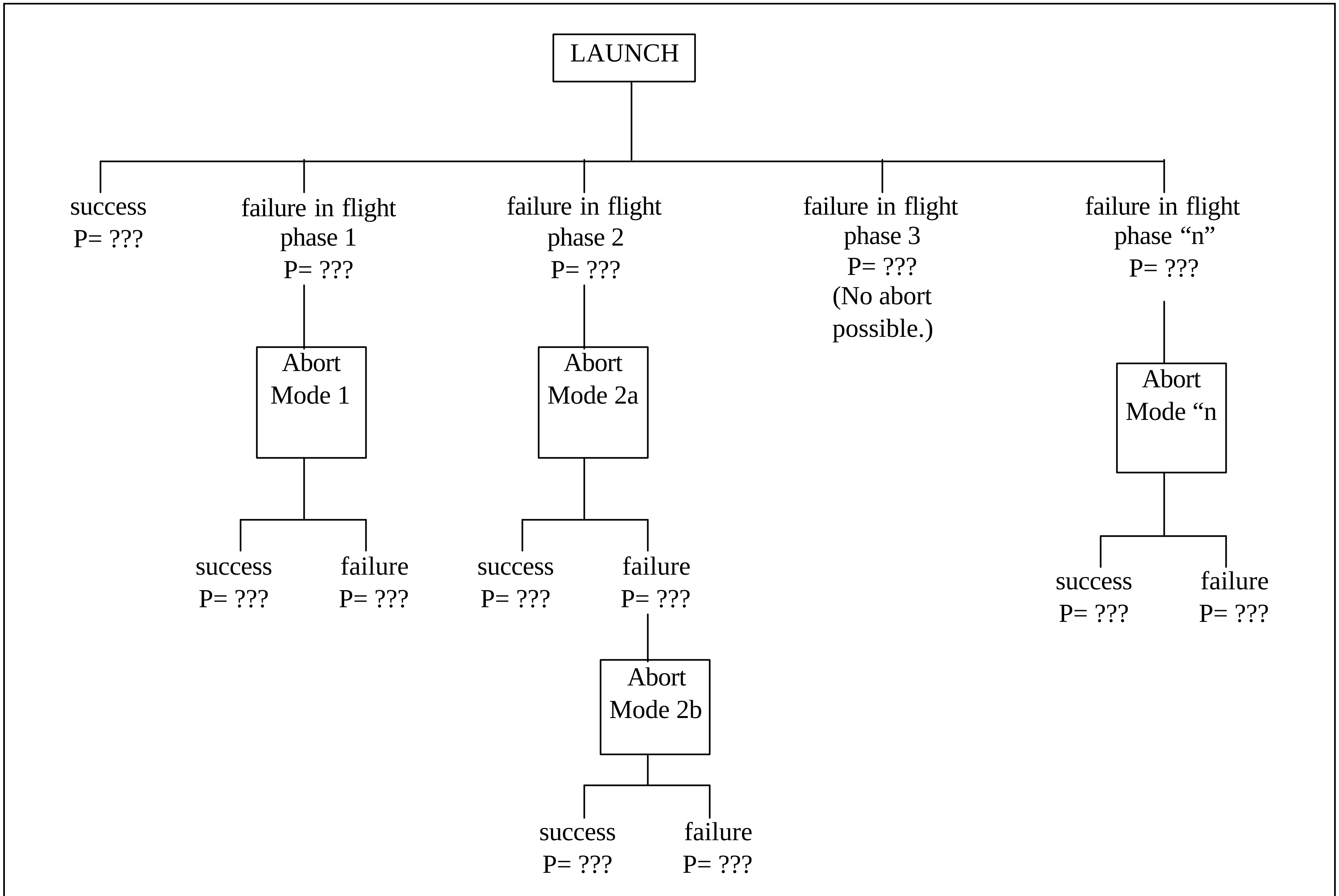

Figure 4 - Top Level Event Probability Tree for a Hypothetical Reusable Launch Vehicle

developing a broad technical understanding of the vehicle's strengths and weaknesses, only cursory involvement in the design and review process is necessary. With RLVs this is no longer the case.

For a variety of reasons, RLVs do not carry conventional flight termination systems. The firewall between a system failure and public casualties is now the vehicle's own abort modes. This operational approach has worked wonderfully for the aviation world where aircraft weighing hundreds of thousands of pounds traveling hundreds of miles per hour routinely over-fly very heavily populated areas around municipal airports.

This more sophisticated firewall, however, drives the regulators to a more technically oriented assessment of system design.

Even if one chose to apply a casualty expectation analysis to RLVs, the lack of a destruct system forces regulators to a more holistic understanding of system design and the programmatic exigencies that spawned it, and offers no workload relief to regulators.

Summary

In summary, there are a number of issues raised by a casualty expectation analysis to the emerging RLV industry.

1. Casualty expectation analyses are technically unsound. Absent a statistically valid launch history, theoretical failure probability values are subject to significant uncertainty.
2. Casualty expectation methodology ignores the implications of between-flight maintenance.
3. Because of the plethora of conditions needing analysis, and the lack of confidence in the resulting answers, a casualty expectation analysis imposes an undue burden on RLV developers.

Even if one chose to apply a casualty expectation analysis to RLVs, the lack of a destruct system forces regulators to a more holistic understanding of system design and the programmatic exigencies that spawned it, and offers no workload relief to regulators.

4.0 RLV TEST FLIGHT PROGRAMS (AST OCTOBER 8 LETTER)

4.1 Criteria to Authorize Test Flights

4.1a Licensing or Certification Criteria for Test Flights (submitted by Kistler Aerospace)

RLV test programs serve two primary purposes:

1) to confirm that the system will function as planned (functional integrity), and
2) to confirm that the operational environment to which the system was designed is as predicted (design integrity).

Without test flights, it is impossible to ascertain if the system, in its totality, will perform as planned. The public, however, must be protected until the test is successfully completed. In the case of ELVs, public protection has typically been enforced through the requirement for launch over water and the incorporation of a Flight Termination System in the vehicle design.

RLVs, which represent real company assets, rely upon abort detection and response modes for such safety assurances. Consequently, verification of abort detection and response systems before first flight is critical.

Consequently, in addition to the review of the documents called out in Section 3.1 of this report, it is necessary for the developer to execute some highly integrated test of the system to verify the correct operation of abort detection and response systems. Such a highly integrated test might consist of a Hardware-in-the-Loop (HWIL) test, either with the vehicle itself in the loop on the pad, or with flight hardware in a Systems Integration Laboratory (SIL).

Assessment of these test results should confirm the proper operation of any redundancy management and abort response systems. Successful completion of this type of highly integrated test, along with lower level qualification tests, are the criteria by which test flights may be licensed.

4.1b Multiple Launch Licensing of Complete Test Flight Program

While a thorough test program is necessary in any development, commercial programs require that the tests be expeditious as well. Consequently, licenses for test flight programs should be given for multiple launches within the program rather than each flight. Such a license would be based upon the developer's presentation of a test plan that includes clear success criteria for each test flight, and conditioned upon FAA concurrence that the previous flight met those criteria.

4.1c Definition of Test Flight Program

A test flight may be defined as any flight where the vehicle is being asked to perform in an environment, internal or external, it has not before experienced. Clearly the first flight of a system is a test flight. A subsequent flight, however, is a test flight only if the environment it is required to perform in is different from that of the previous flight.

Developers generally have a required system availability. This availability requirement means that the vehicle must be able to perform in a range of wind, temperature, gust, and other conditions. Developers will need to "explore the envelope" of flight conditions in order to demonstrate capability and realize the level of availability they require.

Flights to "explore the envelope" are test flights. However, developers may approach such a sequence of flights differently. Some may attempt a sequential exploration, while others may intersperse test flights with purely commercial flights within already experienced conditions. In either case, the test program consists only of those flights actually exploring the internal and external environments.

4.1d Criteria for Over-Flight of Populated Areas

An RLV should be licensed to over-fly a populated area if the flight conditions anticipated are within those already demonstrated in a test flight. Among the flight conditions to be considered, assuming the vehicle thrust level and other key performance parameters remain the same, are

1. Maximum dynamic pressure (max q)
2. Maximum bending moment (max q-alpha)
3. Gust conditions (May be incorporated into 2 above.)
4. Payload mass

4.2 Criteria for Transitioning from Test to Commercial License (submitted by Kistler Aerospace)

Before addressing the criteria for transitioning from test to commercial license, it is necessary to consider the characteristics of RLV test flight programs.

RLV test flight programs are not designed as developmental (research) flights. Early supersonic aircraft flights and early missile test flights were designed to determine a then completely unknown environment or to test new materials and components. There was little or no operational experience in these flight regimes, and modeling capabilities were crude at best. Fundamental research flights were required to advance the technology. This is not the case with RLVs.

RLV test flight programs are also not designed as safety demonstrations. Commercial aircraft certification programs require the aircraft manufacturer to demonstrate that the aircraft can accomplish certain activities and maneuvers while keeping a hypothetical passenger safe from life threatening environments (impact injury, smoke, reduced cabin pressure, etc.). With a few exceptions that may require special rules, RLVs carry no paying passengers and, hence, so long as the vehicle maintains its integrity, it poses no immediate threat to life.

RLV test programs, then, serve two primary purposes:

1) to confirm that the system will function as planned (functional integrity), and
2) to confirm that the operational environment to which the system was designed is as predicted (design integrity).

With this realization it also becomes clear that the RLV flight test program cannot be divorced from the overall Verification and Validation program, nor can a flight test program necessarily serve as the sole indicator of system integrity. Moreover, there may be system features and operations whose design and function cannot be confirmed in a flight test but, rather, may require demonstration in some other venue such as an integrated hardware-in-the-loop test. Specific instances of this situation are presented as part of the discussion below.

FUNCTIONAL INTEGRITY

As discussed above, one of the two primary purposes of an RLV test program is to confirm that the system will function as planned. This may be called the system's functional integrity. Two kinds of functional integrity need to be demonstrated as part of an RLV test program - nominal functional integrity and off-nominal functional integrity.

Nominal Functional Integrity

Nominal functional integrity is established through an incremental process that begins with lower level tests on components and sub-systems. Developers conduct these tests in accordance with their Verification and Validation Plans. Pre-launch test and checkout activities enable further confidence in the vehicle's proper assembly. Finally, the vehicle's first flight confirms that all components and assemblies were integrated correctly.

Clearly, successful completion of the first flight is the ultimate success criterion in regards to nominal functional integrity. A successful test flight implies the successful completion of all lower level assembly and testing. As such, monitoring of the test flight and review of the test report(s) provides regulators with an expedient check on all levels of functional integrity without the need to review each and every test result.

If the sole purpose of an RLV test program, then, were to confirm the nominal functional integrity only, the monitoring of this one flight would be sufficient. In this instance, the RLV test program coincides with the conventional ELV paradigm where each vehicle receives only one complete test of nominal functional integrity.

Off-nominal Functional Integrity

As mentioned earlier, there may be system features and operations whose design and function cannot be confirmed in a flight test. Specific examples may include redundancy management routines and abort responses.

Due to the plethora of possible scenarios under which these features may be called upon, it is not economically feasible to demonstrate the off-nominal functional integrity of the vehicle in actual flight. In addition, an efficient system will be designed such that the execution of extreme abort maneuvers will consume design margin and push vehicle structures to yield conditions. This effectively renders the vehicle unusable after its return, a condition economically detrimental to the operator.

(I will note here that commercial aircraft certification programs do demonstrate the off-nominal functional integrity of a number of systems. However, in a program that anticipates the sale of hundreds of vehicles, and in which the cost per flight is measured in six figures or less, such demonstration is affordable. Moreover, the carriage of passengers makes injury or death due to a malfunction more likely for an aircraft than for an RLV, and justifies the added caution.)

The method of demonstrating off-nominal functional integrity will vary depending upon the features and functions being exercised. They should, however, be demonstrated at the highest level possible to ensure that the full integration of hardware elements and the hardware/software interface is exercised in as close to flight configuration as possible.

This approach typically results in the demonstration of off-nominal functional integrity through an integrated hardware-in-the-loop (HWIL) test that incorporates actual flight hardware and flight control software. With such a tool, the full range of abort responses and redundancy management logic branches can be exercised and evaluated.

DESIGN INTEGRITY

Design integrity means that the operational environment to which the system was designed is as predicted. There are two kinds of environments that must be confirmed - internal environment and external environment.

Internal Environment

So long as the operational scenario remains the same, the internal environment generally varies little from flight to flight. Consequently, the first flight of the vehicle serves to confirm the design integrity with regard to internal environments and no subsequent flight is required.

External Environment

The external environment can vary greatly from flight to flight. Consequently, the first flight of the vehicle serves to confirm the design integrity with regard to the external environment on that particular day, but is not adequate to confirm design integrity for all expected environments. Confirming the design integrity for the expected range of external environments is often called "exploring the envelope." This process involves selecting the launch environment or changing the flight parameters in such a way as to incrementally confirm design integrity under varying environmental conditions with each flight.

With this background, it is now possible to discuss the criteria for transitioning from a flight test program to a commercial license.

The primary question that must be addressed to enable this transition is "Has the vehicle's integrity been demonstrated?" Or, more specifically, "Has the vehicle's functional integrity, both nominal and off-nominal, and design integrity under the internal and external environments for the proposed flight conditions, been confirmed?"

In brief, the answer is "yes" if:

1) the vehicle's off-nominal functional integrity has been demonstrated in a high level test such as an integrated hardware-in-the-loop test;
2) the vehicle's nominal functional integrity has been demonstrated in at least one test flight;
3) the vehicle's design integrity in regards to the internal environment has been demonstrated in at least one test flight;
4) the vehicle's design integrity in regards to the external environment to be flown through has been demonstrated in a test flight.

Of these, only the demonstration of the vehicle's design integrity in regards to the external environment to be flown through requires more than one test flight. Or, conversely, the vehicle is operational and may receive a commercial license immediately after the successful return from its first test flight. However, its operation is limited to flight in some designated region of its design (external environment) envelope, a region centered on the conditions experienced in the test flight.

If the vehicle's developer wishes to fly through external environmental conditions significantly different from those demonstrated on the first flight, the developer must plan a flight test program that prudently explores the design envelope to demonstrate design integrity in those regions of the envelope. The number of flights in such a test program will vary depending upon the concept features and the size of the envelope desired by the developer. However, as each point in the design envelope is successfully demonstrated, the commercial license is expanded to cover those conditions.

5.0 HUMAN RATING SAFETY STANDARDS (AST OCTOBER 8 LETTER)

5.1 Life Support Requirements (Submitted by Rotary Rocket)

It is clear that the safe operation of a piloted[104] RLV is related to the well being of the pilot(s), and their level of skill in operating the vehicle. Therefore:

i. ***All individuals on board should have some form of redundant life support system at their disposal.***
ii. ***Life support systems should include specifically an oxygen supply and environmental controls.***

(Submitted by Vela Technology Development, Inc. in place of the italicized information above)

iii. Life support and environmental control should be provided so as to insure survivability of personnel in a fashion consistent with aircraft survivability.

5.2 Training and personnel requirements

Recommendation 1
(Submitted by TGV Rockets)

Rather than require human-rated certification for RLVs, launch licenses combined with a waiver of liability provide adequate regulation for safe operations. If AST decides to pursue additional licensing options, the same framework used for pilots of experimental aircraft should be used for manned RLVs. This requires the pilot to hold an operator's license for the category of experimental vehicle, i.e.- fixed wing or rotary wing. In the case of rocket-powered vertical takeoff/vertical landing vehicles (similar to the DC-X), either a fixed wing or a rotary wing operator's license be considered acceptable.

Although no further regulation should be required, the following would be good industry practice:

- For the duration of the flight test program, the pilot in command should be a graduate of a military or civilian test pilot school. (Note: this recommendation does not extend to the co-pilot).
- At the end of the flight test program, the pilot in command would no longer need to be a test pilot school graduate.
- The pilot in command should complete a training program developed by the RLV operator.

[104] A distinction is drawn between manned and piloted RLVs. A piloted RLV is one where the people on board have the ability to control the vehicle. A manned RLV would be an autonomous vehicle carrying passengers.

Recommendation 2
(submitted by Rotary Rocket)

The same framework used by the Associate Administrator for Regulation and Certification (AVR) for experimental aircraft should be used for RLVs. Under that framework, the only requirement for a pilot is that they hold an operator's license for the category of aircraft into which the experimental vehicle falls, i.e. rotary wing, fixed wing. This is based on the fact that no specific training program or standard qualifications are available for an experimental vehicle; therefore a vehicle category license is the closest alternative available to ensure a pilot has some related operational experience.
For RLVs, therefore:

i. The flight crew should include one individual designated as the pilot-in-command, while other flight crew may or may not be involved with the operation of the vehicle
ii. The pilot-in-command should hold an operator's license for the vehicle category that most closely resembles the operation of the RLV

Further, due to the experimental nature of RLV flight-test programs:

iii. During the RLV flight-test program, the pilot-in-command should also be a graduate of a recognized test pilot school
iv. The pilot-in-command undergo a training program, the content of which is determined by developer of the RLV

These recommendations stem from the fact that test pilots are trained specifically to recognize and respond to anomalous situations expeditiously. They have the experience and training required to assess the risk in any given situation and respond to it accordingly. Furthermore, developers are the most knowledgeable entity available on the design and expected operation of a new vehicle. Combined with the experience of a trained test pilot, a developer can produce a completely adequate training program for an experimental vehicle.

As a final note on this issue, once an RLV design has completed its experimental program and changed its status to operational, the test pilot requirement (item iii) be dropped to include any pilot (item ii) who has undergone the RLV pilot training program (item iv).

Recommendation 3
(submitted by Vela Technology Development, Inc.)

Medical qualification for people supporting and traveling in space should be pretty much the same as it is currently for general aviation. No one, NOT EVEN NASA, has any experience with general passenger travel into space. However, just as with aircraft travel, early on the environment was new, somewhat more stressing than other forms of transportation, and limited to the wealthy. As travel in the new medium became more routine & hardware became more sophisticated, the stresses on the passengers became less and less. Today, there is a market place that has experience in the medical screening of its passengers. This market place subjects its clients to stresses that are often substantially above the normal everyday. That is the adventure tour market place. These folks routinely conduct adventurers in environments that not everyone would consider benign. And, they routinely address the medical questions of appropriate exposure. Use this experience as a starting place for early space travel. Other than 1) weightlessness, 2) some increase in g-loads, 3) some possible brief increase in vibe/sound levels, and 4) the newness of it all, nothing about this new frontier should present a problem not already addressed routinely in the adventure tour and airline industries! Natural extensions of these procedures should be adequate to space travel as well. Don't let NASA convince you otherwise; to do so would be to perpetuate a myth. The days of "the right stuff" are largely by-gone! The NASA experience base comes from the world of converted, high acceleration munitions. The commercial market place for space (and trans-atmospheric) travel will simply not tolerate that approach. Upgrade training for today's airline crews should be minimal and ultimately, training for passengers should be largely non-existent. We, the developers, will be forced to make it benign and routine or we won't survive."

5.3 Functional Responsibility for Public Safety-Related Operations (submitted by Rotary Rocket)

Although difficult to interpret clearly, it was assumed that "functional responsibility for public safety-related operations" refers to the assignment of responsibility for operational decisions on piloted RLVs. If this is the case, the same framework that is used for aircraft should be applied to RLVs. Specifically that:

i. The RLV pilot-in-command has ultimate responsibility for all operational decisions, while ground personnel offer information and advice on decisions

Further:
From the RLV Working Group discussion on this draft response, it was noted that NASA reports on manned systems would be a relevant source for gathering historical information before developing ***Human Rating Safety Standards – specifically Man-Systems Integration Standards NASA-STD-3000 Volume I and II, July 1995.*** **(high-lighted information provided by Vela Technology Development, Inc)**

There is an abundance of applicable material in this report to help RLV developers design their piloted or manned launch vehicles, but these reports should not be directly translated into a set of standards for commercial space operations. These reports were created for a purpose other than reusable commercial vehicles. Therefore, a set of standards or recommendations for manned space systems could be derived from these reports and the operational experience of commercial reusable systems.

6.0 Comments on Guidelines for Re-entry Licensing (submitted by Kistler Aerospace)

6.1 Criterion 1: Public Expected Casualty

<u>(See Section 3.3)</u>

6.2 Criterion 2: Safety Process Methodology

In considering a Safety Process Methodology, the FAA should remain open to different approaches used by developers themselves.

In general, the achievement of vehicle return is a "stricter standard" than FAA safety concerns. It is more difficult to ensure that a vehicle returns intact than to ensure that a vehicle is operated without causing casualties among the general public. RLV developers are therefore motivated by their financial interests to minimize the chances of a failure that would lead to loss of vehicle.

The developers, being more aware of the relative strengths and weaknesses in their design, may choose to undertake analysis of some features to a deeper level than others.

6.3 Criterion 3: Human Intervention Capability

Criterion 3 requires the capability for human initiation of abort actions during ascent regardless of any automatic abort detection and response capability.

Criterion 3 is unnecessarily restrictive. It should be noted here that Russian launch systems have been flying using only an onboard abort detection and response capability since the beginning of space exploration. Recently, Boeing Sea Launch has been licensed using only an onboard abort detection and response capability.

If the human intervention capability envisioned by the FAA includes a ground "man-in-the-loop," then American RLV developers will be required to contract for expensive downrange communications capability either through an antenna network or TDRSS. (Two-way communications is more expensive than simple telemetry down-link.)

If the human intervention capability envisioned by the FAA includes a "pilot-in-the-loop," then American developers will be required to produce only piloted systems. Advances in computer technology and processing speeds make automatic abort detection and response more than reliable enough to meet FAA safety concerns.

6.4 Criterion 4: Positive Human Initiation of Reentry Activities

Criterion 4 requires that the system include fail-safe assurance that reentry activities cannot be initiated prior to human verification that safety critical systems are active and the vehicle is properly configured for reentry.

Criterion 4 is unnecessarily restrictive. It should be noted that even human monitored systems rely upon computer-controlled sensors and reporting mechanisms to deliver system status to the human monitor. Considering the extent to which existing systems already rely upon such automatic status monitoring, the implementation of a fully automatic verification system should not be discouraged.

If the human intervention capability envisioned by the FAA includes a ground "man-in-the-loop," then American RLV developers will be required to contract for expensive downrange communications capability either through an antenna network or TDRSS. (Two-way communications is more expensive than simple telemetry down-link.)

If the human intervention capability envisioned by the FAA includes a "pilot-in-the-loop," then American developers will be required to produce only piloted systems. Advances in computer technology and processing speeds make automatic abort detection and response more than reliable enough to meet FAA safety concerns.

Computer technology and processing speeds make automatic system status verification a cost-saving alternative to human verification activities without compromising safety.

6.5 Criterion 5: Flight Data Monitoring and Recording

Criterion 5 requires real-time transmission of key system status to a control center which has command capability and decision making responsibility "during the entire launch phase and at other safety critical decision points."

The transmission of real-time flight-critical monitoring information is necessary in the event a failure needs to be understood in an accident analysis. But appropriate mission rules followed by a ground controller will yield the same result when followed by system software. It is not necessary for the ground center to retain command capability since controllers will simply follow the previously identified mission rules.

6.6 Criterion 6: Non-nominal Re-entry Risk Mitigation

Criterion 6 requires the ability to mitigate re-entry risk by re-targeting a vehicle whose controllability is in question to an alternate site such as the open ocean. Alternatively, a mechanism that violates the integrity of the TPS in such a situation, thus causing the vehicle to break up during reentry, may be incorporated.

Re-entry generally requires specific atmospheric entry conditions (altitude, velocity vector, vehicle attitude, and rates. A vehicle, even one with a thermal protection system, is extremely unlikely to survive a random re-entry. The FAA should allow for the developer to show by analysis that the developer's vehicle is unlikely to survive a random reentry in lieu of a requirement to retarget or compromise TPS integrity

(Submitted by Vela Technology Development, Inc.)

Since no such requirement is levied upon aircraft under non-nominal flight conditions, none should be levied upon spacecraft

6.7 Criterion 7: Over-Flight of Populated Areas

(Reference paragraph 4.1d)

Criterion 7 requires the avoidance of densely populated areas regardless of the outcome of the casualty expectation analysis. The allowable population density ceiling will be determined for each system separately depending upon its casualty area.

This item seems to give the FAA arbitrary veto power over a launch license. The uncertainty represented by this item would discourage investment in otherwise promising systems.

If this item is in place, then what is the purpose of Item 1? If Item 1 is in place, then what is the purpose of this item?

6.8 Criterion 8: Reentry/Landing Site Risks

Requires that the 3-sigma dispersion of a RLV landing operation be entirely contained within the planned landing site. In addition, risks to the public from nominal reentry shall not exceed 1E-6 for areas surrounding the site.

The material accompanying Criterion 1 states that the 30E-6 risk may be allocated in any fashion between ascent and re-entry events. Criterion 8 appears to contradict this statement.

The sizing of a planned landing site is an economic decision based upon the cost to prepare the site per square foot, and the likelihood that the vehicle will land outside a site of a given size. The requirement that the 3-sigma dispersion be entirely contained within the planned landing site removes this decision from the developer. The requirement should state that the 3-sigma dispersion be entirely contained within a controlled landing area consisting of a landing site and any surrounding safety zone.

6.9 Criterion 9: Pre-planned, Pre-approved Staging Impact Points, Contingency Landing Sites, and Contingency Abort Sites

Requires the identification and regulatory approval of the above mentioned sites. Also requires that these sites avoid air traffic routes or that mitigation measures (airspace clearance) be taken before launch to ensure there are no aircraft over the site at the time of reentry.

Prior Kistler experience showed that when Kistler identified such sites, the FAA required that an environmental analysis be done for each of them regardless of how likely they were to be used. Considering the small likelihood that these types of sites will ever be used, such a requirement is unwarranted. Kistler considers such sites the equivalent of a "pilot looking for a cornfield," and the FAA does not require environmental analysis and regulatory approval for every possible place an aircraft might come down.

The requirement to avoid air traffic routes or to clear them before commencing an emergency re-entry (which implies that air routes would need to be cleared for launch operations as well), is overly restrictive. It will incite the air transport industry to oppose RLV operations, and essentially confine RLV operations to established national ranges.

6.10 Criterion 10: Flight Test Demonstration Program

(Reference paragraph 4.0)

Requires that flight tests demonstrate abort and recovery maneuvers.

Abort and recovery operations are, by definition, high risk, high stress maneuvers, much more so than normal operations. Off-nominal operations are demonstrated in aircraft certification programs because the cost per flight is measured in the thousands of dollars, and the vehicle production run is likely to be in the hundreds, if not the thousands. Flying a single aircraft in such high stress situations is justified in gaining type certification for the model.

For RLVs, whose per flight costs are significantly higher and whose production runs are much lower, risking the damage or destruction of a vehicle in demonstrating abort and recovery maneuvers is costly. Considering the small likelihood that such maneuvers will ever be required, risking damage or destruction of a vehicle in demonstration of these maneuvers is unwarranted.

Instead, industry and the FAA should develop an analysis regime that will adequately meet the FAA's need to ensure safety, and the developer's need for a cost-effective flight test program

6.11 Criterion 11: Pre-flight Inspection and Checkout

(To be supplied)

7.0 OPERATIONS REGULATIONS (Submitted by Kistler Aerospace)

The RLV Working Group recommends the revision of certain existing FAA regulations and practices affecting launch vehicle operations and development if the full potential of RLVs is to be realized.

7.1 Authorization for Routine Commercial Launch Operations

Existing regulations contemplate a launch license for a single launch or group of defined launches. RLVs will be capable of routine operations on short notice (*see below*).

To accommodate routine launch operations, the RLV Working Group believes that the licensing regime should evolve toward authorization of regular flights within defined parameters and payload classes. Appropriate notification and submission of information of flights under the license would be required. The FAA would remain empowered to intercede in planned operations in appropriate circumstances.

If licensing for routine flight operations were not developed, the FAA would burden the emerging RLV industry with redundant, duplicative and unnecessary licensing requirements.

7.2 Authorization for Short Notice Launches

RLVs make possible short-notice deployment of payloads. If pre-flight licensing requirements prevent launches on notice of days or even hours, regulation will nullify an important new service offered and competitive advantage enjoyed, by RLVs.

Emerging commercial satellite constellations must replace failed satellites or risk disruptions in service. Presently, satellite constellations incorporate redundant capacity and utilize on-orbit spares to address this risk.

RLVs will allow customers to launch in a matter days, if not hours. This added service would permit satellite constellations to maximize the use of their on-orbit assets, store spares safely on the ground, and insert replacement satellites into their constellations precisely.

Further, the emerging satellite constellations are raising venture capital much like RLV developers. If short-notice launches on RLVs can alleviate significant fabrication, launch and development costs associated with maintaining on-orbit spares and redundant capacities, the introduction of RLV short-notice capabilities will facilitate the emergence of broad-scale satellite communications.

This service affords RLV operators a significant competitive advantage vis-à-vis ELVs. But if launch notification requirements require significant advance notice, this competitive advantage and its benefits for customers will be lost. The RLV Working Group recommends that the launch notification requirements be shortened in conjunction with the development of licensing for routine operations.

7.3 Importance of Financial Responsibility Regime

The statutory indemnity regime established under the commercial space law sunsets in December 1999. The RLV industry is in rapid development. The stability of this statutory indemnity regime is critical to investors, contractors and customers of the RLV industry. The RLV Working Group accordingly supports the extension of this provision.

7.4 Environmental Approvals

The RLV Working Group supports expedition in environmental processes associated with launch licensing and spaceport development. The equipment and materials used in RLV ground operations differ little from those used in many other heavy industrial operations. And the environmental impacts of launch systems are well characterized. In light of this, environmental impacts caused by RLV's should be treated as relatively known quantities and not as novel issues requiring research and multiple levels of approval.

8.0 COMSTAC RLV WORKING GROUP (Submitted by Kelly Space & Technology)

8.1 Members and Procedures

The COMSTAC RLV WG currently consists of approximately 100 persons, of which approximately 20 are active participants in the development of regulation recommendations. The contact list appears as Table 3 in this report. The WG meets at approximately 30-day intervals on both the East and West coasts. East Coast meetings are normally held in Washington DC at either FAA or DOT headquarters. West Coast meetings are normally held at the AIAA West coast regional headquarters in El Segundo, CA, with off-site meeting participation facilitated by teleconference.

The RLV WG understands that FAA/AST is currently preparing specific procedures to be used for all COMSTAC working groups. At the present time, the RLV WG is proceeding in accordance with the general understanding of WG members regarding the charter provided by AST at the inception of the WG in September 1998.

8.2 Final Report

As noted in paragraph 1.0, Executive Summary, this interim report will be supplemented by additional incremental inputs to be provided prior to official release of the NPRM. It is anticipated that the final report will be submitted in April or May 1999.

Table 3

Commercial Space Transportation Advisory Committee (COMSTAC)
Reusable Launch Vehicle (RLV) Working Group Contact List

NAME	COMPANY	TELEPHONE	FAX	E-MAIL
Ackerman, Pete	Boeing/Rocketdyne	(818) 586 - 7381	(818) 586 - 0814	peter.c.ackerman@boeing.com
Aldrich, Arnold	LMA	(703) 413 - 5887	(703) 413 - 5886	
Aldrich,Eleanor	AIAA	(703) 264 - 7522	(703) 264 -7551	eleanora@aiaa.org
Bachner, Herb	FAA/AST	(202) 267 - 7859	(202) 267 - 5463	herbert.bachner@faa.gov
Bahn, Pat	TGV Rockets	(301) 451 - 5180	?	prb@clark.net ?
Ballard, Bob	Vela Technology Dev., Inc.	(703) 707 - 6252	(703) 707 - 6254	Rb3balla@aol.com
Berry, Jim	Boeing Co.	(714) 896 - 3559	(714) 896 - 1244	
Birkeland, Paul W.	Kistler Aerospace Corporation	(425) 889 - 2001	(425) 803 - 3303	pbirkeland@kistleraero.com
Boyland, Jack	United Space Alliance	(281) 212 - 6144	(281) 212 - 6179	john.s.boyland@USAHQ.United.Space.Alliance.com
Brandenstein, Dan	Kistler Aerospace Corporation			
Brinker,Stanley R.	GPS Solutions,Inc.	(941) 749 - 1278	(941) 748 - 1359	SRBJKB@aol.com
Bronco,Dennis	Lockheed Martin Corporation	(301) 897 - 6585	(301) 897 - 6929	dennisbronco@lmco.com
Brown, Terry	FAA/ATA-400	(202) 267 - 9193		terry.brown@faa.gov
Buzzatto, John	Scitor Corporation	(310) 535 - 6321	(310) 535 - 6301	jbuzzatto@scitor.com
Carter, Elizabeth	AIAA	(310) 643 - 7515	(310) 643 - 7509	elizabethc@aiaa.org
Chase, Emily	Chase Communications	(909) 798 - 6150	(909) 798 - 6150	EmilyChase@aol.com
Clapp, Mitchell Burnside	Pioneer Rocketplane	(805) 734 - 3165	(805) 734 - 9745	mitchell@rocketplane.com
Cohen, Aaron	Texas A & M University	(409) 862 - 2776		Acohen@mengr.tamu.edu
Coleman, Kelvin	FAA/AST-100	(202) 267 - 7972		kelvin.coleman@faa.dot.gov
Cone, Robert	Lockheed Martin Corporation	(408) 543 - 3163	(408) 543 - 3004	robert.r.cone@lmco.com
Cramer, Karen	TGV Rockets	(202) 488 - 1458		karen.cramer@ ?
Dalby, Royce	Lockheed Martin Corporation			Qosmonaut@aol.com
Davis, Bob	Kelly Space & Technology, Inc.	(909) 382 - 5674	(909) 382 - 2012	bdavis@kellyspace.com
Dean, Bob	United Space Alliance	(281) 212 - 6162	(281) 212 - 6372	Robert.W.Dean@usahq.unitedspacealliance.com
Eberlin, Harry	Crown communications	(202) 785 - 2600	(202) 785 - 2626	h.eberlin@crown.com
Elias, Antonio	Orbital Sciences	(703) 406 - 5514	(703) 406 - 3509	ae@orbital.com
Etchart,Mike	FAA/AST-200	(202) 267 - 8568		michael.etchart@faa.gov
Flores, Carole C.	FAA-AST	(202) 267 - 8353	(202) 267 - 5473	carole.flores@faa.gov
Forge, Dave	Boeing Co.	(714) 896 - 5544	(714) 896 - 5807	

Table 3, (continued)

Commercial Space Transportation Advisory Committee (COMSTAC) Reusable Launch Vehicle (RLV) Working Group Contact List

NAME	COMPANY	TELEPHONE	FAX	E-MAIL
French, Jim	AIAA	(703) 264 - 7500	(703) 264 - 7551	jimf@aiaa.org
French, William R.	Avalon Associates International	(703) 821 - 2620	(703) 821 - 3421	wrfrench@erols.com
Fudge, Mike	ITT Industries (FAA contractor)	(703) 329 - 7372	(703) 960 - 7047	mike.fudge@ssc.de.ittind.com
Fuller, Paul	Rocket Systems	(719) 594 - 6761	(719) 594 - 6759	
Gaubatz, Bill	Universal Space Lines	(949) 476 - 3380		gaubatz@spacelines.com
Goldstein, Allen E.	Aerospace Corporation	(310) 336 - 5650	(310) 336 - 8843	goldstein@courier3.aero.org
Greer, Paul	Phaneuf Associates, Inc.	(202) 898 - 1410	(202) 898 - 1455	
Gress, Ronald K.	FAA-AST	(202) 267 - 7985	(202) 267 - 5473	ron.gress@faa.dot.gov
Gump, David	Rotary Rocket Company	(703) 841 - 9500	(703) 841 - 9503	dgump@lunacorp.com
Hieb, Rick	Allied Signal	(410) 964 - 7255	(410) 964 - 7265	richard.hieb@alliedsignal.com
Himaras, Nikos	FAA/AST	(202) 267 - 7926	(202) 267 - 5450	nick.himaras@faa.dot.gov
Hoeser Steven J.	Vela Technology Dev., Inc.			
Holder, Livingston	Boeing Company	(253) 773 - 9067	(253) 773 - 6399	livingston.l.holder@boeing.com
Hudson Gary C.	Rotary Rocket Company	(650) 298 - 3308	(650) 298 - 3301	ghudson@rotaryrocket.com
Jackson, Stewart	FAA/AST	(202) 267 - 7903		stewart.jackson@faa.dot.gov ?
Kelly, Mike	Kelly Space & Technology, Inc.	(909) 382 - 5641	(909) 382 - 2012	mkelly@kellyspace.com
Keltner, Robert	Kelly Space & Technology, Inc.	(909) 382 - 5646	(909) 382 - 3437	bkeltner@kellyspace.com
Klevatt, Paul	Boeing Company			
Kronmiller, Kate	United Space Alliance	(703) 412 - 6824	(703) 412 - 6825	Kate.B.Kronmiller@USAHQ.United.Space.Alliance.com
Kyger, Timothy B.	Universal Space Lines	(703) 820 - 3164	(703) 820 - 3509	kyger@spacelines.com
Lane, Carol	Lockheed Martin Corporation	(408) 543 - 3034	(408) 543 - 3004	carol.lane@lmco.com
Larsen, Chuck	FAA/AST	(202) 267 - 7908	(202) 267 - 5463	chuck.larsen@faa.dot.gov ?
Lauer, Charles J.	Pioneer Rocketplane	(313) 761 - 1771	(313) 761 - 1735	
Leonard, Stephen C.	International Space Brokers	(703) 841 - 1334	(703) 841 - 0525	stephenl@isbworld.com
Lindberg, Bob	Orbital Sciences Corp./X-34	(703) 406 - 5441	(703) 421 - 2057	lindberg.bob@orbital.com
Maday, Randal	FAA/AST	(202) 267 - 9051	(202) 267 - 5473	
Martin, Patrick	FAA/AST-200	(202) 267 - 9237		patrick.a.martin@faa.gov
Matthews, Reggie	FAA	(202) 267 - 8783	(202) 267 - 9328	reggie.matthews@faa.dot.gov

Table 3, (continued)

Commercial Space Transportation Advisory Committee (COMSTAC) Reusable Launch Vehicle (RLV) Working Group Contact List

NAME	COMPANY	TELEPHONE	FAX	E-MAIL
McDevitt, Joyce	Futron Corporation	(202) 488 - 2939	(202) 488 - 7863	JMcDevit@Futron.com
McKeon, Michael J.	Boeing Company	(818) 586 - 5919	(818) 586 - 9234	michael.j.mckeon@boeing.com
Meade, Carl	Lockheed Martin Skunk Works	(805) 572 - 3908	(805) 572 - 5941	carl.meade@lmco.com
Meuser, Robert E.	Kistler Aerospace Corporation	(202) 337 - 9463	(202) 337 - 3639	bmeuser@kistleraerospace.com
Minami, Henry M., Jr.	Boeing Company	(818) 586 - 7850	(818) 586 - 0145	henry.m.minami-jr@boeing.com
Mitchell, Ruben	FAA/AST-100	(202) 267 - 7900	(202) 267 - 5450	ruben.mitchell@faa.gov
Miyaoi, Clifford	Allied Signal	(310) 721 - 0605	(310) 860 - 3375	clifford.miyaoi@alliedsignal.com
Molvar, Jan	Scitor Corporation	(408) 745 - 8345	(408) 745 - 8296	jmolvar@scitor.com
Moore, Roscoe	Student	(703) 553 - 0270	(703) 904 - 0571	roscoe93@aol.com
Mueller Gary F.	Aerospace Corporation	(310) 336 - 7409	(310) 336 - 4554	gary.mueller@aero.org
Oram, Bert	Phaneuf Associates, Inc.	(202) 898 - 1420	(202) 898 - 1455	
Parker, Brenda	FAA	(202) 267 - 8308	(202) 267 - 5473	brenda.parker@faa.gov
Piantes, Anthony H.	Aerojet	(202) 828 - 6861	(202) 828 - 6849	tony.piantes@aerojet.com
Ray, Bob	TGV Rockets	(253) 875 - 2837	(253) 875 - 2851	bobray@tgv-rockets.com OR ix@netcom.com
Rey, Rene J.	Allied Signal	(805) 257 - 6020	(805) 257 - 8423	rjrey@pop.net
Rising Jerry J.	Lockheed Martin Corporation			
Roach, Joe	Lockheed Martin Skunk Works	(805) 572 - 4332	(808) 572 - 5941	joe.roach@lmco.com
Rosenberg, Esta	FAA, Office of Chief Counsel	(202) 366 - 9320	(202) 366 - 9313	esta.rosenberg@faa.gov ?
Rosepink, Ronald K.	Space Access, LLC	(303) 478 - 4745	(303) 693 - 2001	RonRsepink@aol.com
Ruth, Edward	Aerospace Corporation	(310) 336 - 5713	(310) 336 - 4554	edward.k.ruth@aero.org
Sargent, Darryl	Draper Laboratory			dsargent@draper.com
Satchell, Larry D.	Boeing Company	(714) 896 - 2526	(714) 896 - 4789	larry.d.sarchell@boeing.com
Schena, Ron	ASTI (AFRL/VSDV-X)	(505) 846 - 5928	(505) 846 - 8930	schenar@plk.af.mil
Schnaars, Jayne	Boeing Company	(562) 922 - 3727	(562) 922 - 1040	jayne.schnaars@boeing.com
Schondel, Patrick	Boeing Company	(703) 465 - 3206	(703) 465 - 3020	pat.schondel@boeing.com
Schroeder Franceskia	Winthrop, Stimson	(202) 775 - 9876	(202) 833 - 8491	schroederf@winstim.com
Shaver, Deborah	ICF Kaiser	(703) 934 - 3145	(703) 934 - 3278	dshaver@icfkaiser.com
Siegerman, Paul	Northrup Grumman			SIEGEPA2@mail.northgrum.com
Smith, Clay	Futron Corporation	(2020 488 - 3180	(202) 488 - 7863	csmith@futron.com

Table 3, (continued)

Commercial Space Transportation Advisory Committee (COMSTAC)
Reusable Launch Vehicle (RLV) Working Group Contact List

NAME	COMPANY	TELEPHONE	FAX	E-MAIL
Smith, Patti Grace	FAA/AST	(202) 267 - 7793		patti.smith@faa.gov
Spain, Ron	Allied Signal	(714) 509 - 9682		
Spalitta, Lisa	Lockheed Martin Corporation			lisa.spalitta@lmco.com
Stenovec, Jerry	Boeing Company	(562) 797 - 5384	(562) 797 - 5750	gerald.m.stenovec@boeing.com
Stockmans, Richard	Rotary Rocket Company	(650) 298 - 3314	(650) 860 - 3301	rstockmans@rotaryrocket.com
Tippetts, Tom	GPS Solutions,Inc.	(505) 647 - 0947	(505) 647 - 1459	TomTippett@aol.com
VanKleeck, Julie	Aerojet	(916) 355 - 2020	(916) 355 - 3743	julie.vankleeck@aerojet.com
Vega, Manuel	FAA/AST	(202) 267 - 7795	(202) 267 - 5450	manuel.vega@faa.gov
Vinson, John	Lockheed Martin Skunk Works	(805) 572 - 5752	(805) 572 - 6325	john.w.vinson@lmco.com
Washington, Michon	FAA/AST-100	(202) 267 - 9305		michon.washington@faa.gov
Wiggins, Laurie J.	Boeing Company			Laurie.Wiggins@PSS.Boeing.com
Wong, Ken	FAA/AST-200	(202) 267 - 8465	(202) 267 - 5473	ken.wong@faa.gov
Woodcock, Gordon	Space America, Inc.	(256) 772 - 3666	(256) 772 - 1316	
Wurst, Steve	Space Access LLC	(805) 267 - 4000	(805) 267 - 4009	stevewurst@aol.com
Zapata, Edgar	KSC, NASA	(407) 861 - 3955	(407) 861 - 0042	Edgar.Zapata-1@pp.ksc.nasa.gov