DRAFT

FINAL REPORT
ON RLV LICENSING
APPROACHES

Commercial Space Transportation Advisory Committee
(COMSTAC)
RLV Working Group

April 29, 1999

REPORT CONCURRENCE

(Contractor or Agency concurrence is indicated by logo displayed below)

ASTi
APPLIED SCIENCE & TECHNOLOGY inc.

KISTLER
aerospace
corporation

KST
Kelly Space & Technology

LOCKHEED MARTIN

PIONEER
ROCKETPLANE

rotary rocket
COMPANY

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Vela Technology Development, Inc.

TGV

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EXECUTIVE SUMMARY

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 from 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. The complete draft document "Interim Safety Guidelines for Reusable Launch Vehicles" is presented in this report as Appendix B.

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) has provided the support requested by the FAA to the COMSTAC. In order to provide timely input to the FAA on these regulatory issues, an Interim Report was provided for consideration of adoption in the draft NPRM. A Final Report was timed for anticipated release of the NPRM prior to May 1999. The NPRM was in fact published in the Federal Register on April 21, 1999.

The RLV WG members have expressed a variety of opinions. These divergent opinions are reflected in the report. First, there is an indication of agreement by the developer or consultant with a basic premise that is a response to a specific question or objective provided by the AST. Second, there is a commentary provided by that developer or consultant regarding the question or objective. These agreements and comments appear in Parts 1 and 2 of this report. Two basic approaches to regulation have been proposed; the tailored FAR and a more flexible approach to accommodate the diverse concepts of the various developers. Both are presented in this report as Appendix A.

The COMSTAC RLV Working Group feels that this industry-wide effort has provided a good forum for individual companies to come together to identify and discuss issues affecting the reusable space industry. In order to develop and operate Reusable Launch Vehicles profitably, a regulatory environment is required which provides sufficient flexibility to accommodate the numerous vehicle concepts. Although a broad expanse of subjects has been covered in responding to initial suggestions and guidance provided by FAA/AST, much work remains on the part of government and industry to define an overall regulatory process. This process must encompass the diverse needs of developers and operators of the new reusable transportation infrastructure while ensuring the public safety.

The Working Group acknowledges that this is a status report based on the current experience and depth of analysis provided by the Working Group members. This report should be used as a starting point for development of a FAA/AST governed, industry implemented licensing process. This process would provide the guidelines and criteria leading to safe, verifiable design, manufacture, test, operation and maintenance of reusable space transportation systems.

This report is a consensus document that enjoys the support of the organizations whose logos appear on the Concurrence Page, (i). However, from time to time, and at their discretion, individual companies may take variance at the opinions expressed in the document. It should be noted here that the most important product of the working group is a regulatory framework that outlines a flexible licensing plan. This plan addresses the tailored FAR approach yet provides sufficient flexibility to ensure maximum participation among the development community while safeguarding the public.

In developing the RLV licensing regime, it is suggested that the FAA/AST consider the following:

- Flexibility based upon the FAA's experience and success in regulating both aircraft and expendable launch systems.
- Combine or eliminate, as recommended, objectives that are either confusing or duplicative. It is imperative that the objectives be both concise and understandable.
- Evaluate the developer's test program in light of maximizing the industry's ability to use all modern technologies to minimize the number of test flights. A phased approach is suggested which would be somewhat restrictive for first flights, with

definable criteria that when met would enable expansion of the flight envelope for future flights.

- Plan now for a “Spaceways” concept that ensures a seamless transition from flight test and future integration of aircraft and RLVs while industry is still in the development phase.
- Use the experience of RLV flight operations for evolving the original objectives.

  Negotiate licensing plans with a philosophy that permits further tailoring of each FAA objective to foster the ability of each system to be successful while maintaining the need for public safety.

PART 1

FAA Critical Safety Issues, RLV Working Group Recommendations

(AST October 8 Letter)

Recommendations on Critical Safety Issues

In a letter dated October 8 to Steve Flajser, Chairman of the COMSTAC, Patricia Smith, FAA Associate Administrator for Commercial Space Transportation, asked the COMSTAC to support the AST in their consideration of a number of critical safety issues. In particular, the AST requested advice and recommendations that address:

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; and
C. Human rating safety standards for RLVs in the following areas:
    1. Life support requirements
    2. Training and personnel qualifications
    3. Functional responsibility for public safety-related operations.

While the COMSTAC RLV Working Group has previously responded to this request in its Interim Report, a further response and recommendations are presented in the following pages.

1.1 Item A: Criteria for Defining the Types of Test Flight Programs Required to Allow Over-flight of Populated Areas by RLV's

The Working Group agrees that:

1. A test flight may be defined as any flight in which the vehicle is anticipated to experience internal or external loads that it has not before experienced, or in which substantive changes in hardware or software functionality are to be demonstrated;

2. An RLV should be licensed to over-fly a populated area following successful completion of the flight test program and exhibition of acceptable risk to the public in accordance with the licensing plan.

3. To facilitate commercially viable test programs, any multiple flights comprising a test flight program should be licensed with a single license covering all planned flights.

Attachment to Item A Recommendations

A.1 Comments on Item A Submitted by Kistler Aerospace Corporation

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.

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. Any flight demonstrating a substantive change in system functionality should also be considered a test flight. 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 any previous flight, or substantive changes have been made in vehicle systems.

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. They reflect a change in external vehicle loads. 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.

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 and no substantive changes have been made to vehicle functionality. 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. Thermal loads
5. Acoustic loads
6. Payload mass

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.

A.2 Comments on Item A submitted by Kelly Space & Technology, Inc. (KST)

1.0 Flight tests are of paramount importance in the development of a RLV system. Unfortunately, as has been pointed out by several developers, the cost of each flight test for a RLV compared to that for an aircraft is so much greater, and the production volume for a RLV compared to an aircraft so small, that the cost of numerous flight tests for a RLV system would make RLV programs not viable.

Typical objectives of a development test program are to demonstrate that engineering design and development are complete, design risks have been minimized and that the system meets the engineering and operational specifications. These objectives can be expanded to include demonstrating operational effectiveness and suitability, system utility and identifying the need for system modifications. Ground tests and/or simulation can achieve many of these objectives.

Although a limited number of flight tests are essential to demonstrate operability, the number required can be reduced significantly by rigorous ground tests. The FAA should consider a developer's proposal to conduct rigorous ground tests as an alternative to an exhaustive series of flight tests. Any test program, either ground or flight, enables the developer to learn more about the system's performance, however this is not the primary objective of a flight test demonstration program. The emphasis of the RLV flight test program should be demonstration of performance, not enhancement.

Some RLV developers propose to use as much off-the-shelf (OTS) equipment as possible. This equipment has a demonstrated history of performance and reliability. Extensive ground testing could be performed to evaluate new interfaces and interactions between other subsystems and components while gaining additional history regarding performance of the OTS equipment in the RLV application. The developer should be allowed to use these demonstrated reliabilities not only in E_c or other calculations, but also to provide the FAA with increased confidence that the RLV system will function as predicted in the flight environment.

A typical RLV mission consists of several phases, each with a distinct risk to the public that can be calculated as an E_c or other method acceptable to the FAA. The summation of these risks must not exceed a specific threshold, currently understood to be 30×10^{-6}. Each developer should be allowed to propose an allocation of this total risk to each flight phase, demonstrating this allocation by a method such as E_c or other method acceptable to the FAA. The developer will, naturally, define his operational scenario to obtain maximum benefit of the uniqueness of his approach to minimize risk to the public. The acceptance of such a risk allocation by the FAA would merely recognize this uniqueness and provide the corollary benefit to the developer of a smaller calculated E_c.

Demonstration of abort procedures in a flight test would indeed compromise system integrity. Many developers have pointed out on numerous occasions that the use of minimum, but adequate, design margins is essential to a cost-effective approach to both placing a payload in orbit and delivering a sub-orbital payload. This fact needs to be re-emphasized. The FAA should allow the developer to develop and test abort maneuvers and procedures in a simulated environment.

It is clear that the use of a P_f of 1 for all flight tests is unacceptable. Therefore, it is essential that the FAA and each developer devise an approach to determining a reasonable P_f for flight testing the developer's RLV. This approach should be reflected in the licensing plan established for that RLV.

2.0 Given this background, the following criteria are suggested to allow over-flight of populated areas:

1. Limit the mandatory test flight program to demonstration tests only, defined as: any flight in which the vehicle is anticipated to experience internal or external loads that it has not before experienced, or in which substantive changes in hardware functionality have been made.

2. Allow the developer to use ground and simulation tests to the maximum extent possible.

3. Allow the developer to develop and test abort maneuvers and procedures in a simulated environment.

4. Recognize the demonstrated reliability of OTS equipment in the E_c calculation or other method acceptable to the FAA.

5. Devise an approach to determining a reasonable P_f for the initial flight test. This P_f would be used in calculating the public risk for the initial flight. The P_f could then be revised accordingly for each successive flight, dependent upon the results of the previous flights.

6. Operational flights, subsequent to completion of the Demonstration Flight Test Program, could be conducted over populated areas in accordance with the public risk calculation.

1.2 Item B: Criteria for Transitioning from a Test Flight Program to an Operational Program

The Working Group agrees that

1. A test flight may be defined as any flight in which the vehicle is anticipated to experience internal or external loads that it has not before experienced, or in which substantive changes in hardware or software functionality are to be demonstrated;

2. A system may be declared operational after successful completion of the flight test program in accordance with the licensing plan.

3. Prudent exploration of the design envelope ultimately yields a fully operational system approved for flight in all regions of its design envelope.

Attachment to Item B Recommendations

A.1 Comments on Item B Submitted by Kistler Aerospace Corporation

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 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 a satellite-delivery RLV, and justifies the added caution.)

The method of demonstrating off-nominal functional integrity will vary depending upon the features and functions being exercised, but they should 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. Changes in system functionality, e.g. running the engines at higher thrust or the incorporation of a new thermal protection material, may change the internal environment. Consequently, the first flight of the vehicle serves to confirm the design integrity with regard to internal environments and no subsequent flight is required unless substantive changes have been made in system functionality.

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.

A.2 Comments on Item B submitted by Kelly Space & Technology, Inc. (KST)

1.0 It is essential that a RLV be permitted to over-fly populated areas following completion of the Demonstration Test Flight Program. Although allowed flight corridors should be determined by E_c or similar calculation during both test and operational flights, the goal of RLV operational flights should be similar to those for commercial airlines, i.e. – to operate in a manner supportive of a healthy industry and unfettered by arbitrary limitations, so long as risk to the public is maintained at acceptable levels.

Risk to the public should be calculated in accordance with E_c or other methods acceptable to the FAA. Operational flights should be permitted over populated areas in accordance with the public risk calculation. Transition from a test flight to an operational program should be accomplished by continuous recalculation of public risk dependent upon results of the test flight program. Upon completion of the Demonstration Test Flight Program, this calculation should be the sole determination for public over-flights.

2.0 Given this background, the following criteria are suggested for transitioning from a test flight program to an operational program.

1. Successful completion of the Demonstration Test Flight Program as determined by the FAA.

2. Establishment of an acceptable public risk calculation for any proposed flight corridor.

1.3 Item C: human rating safety standards

1.3.1 Item C.1: Life Support Requirements

The Working Group agrees that

1. There needs to be adequate life support on board to provide for the well being of the crew and any passengers.

Attachments to Item C.1 Recommendations

A.1 Comments on Item C.1 Submitted by Rotary Rocket

It is clear that the safe operation of a piloted[1] 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

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[1] 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.

A.2 Comments on Item C.1 Submitted by Pioneer Rocketplane

There is nothing wrong with requiring redundant life support for passengers. Our expectations are that a pressurized cabin would be primary, with a pressure suit as a backup. However, the FAA should not mandate this except for passengers. If someone wants their flight crew to go in pressure suits only, that’s fine. (Consider an astronaut in EVA. One suit, one life support system.)

A.3 Comments on Item C.1 Submitted by Vela Technology

Aircraft routinely fly at altitudes that would put passengers and crew at risk if they were to lose breathing air/controlled environment—yet they are not required to have redundant oxygen supplies for each individual and certainly do not have redundant and individual environmental controls. We support ONLY that the space ship be required to address crew/passenger safety and not that specific system and/or redundancy solutions be specified.

Thoughts on "Medical Qualification" for Space flight

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 bygone! 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.

A.4 Comments on Item C.1 submitted by Kelly Space & Technology, Inc. (KST)

1.0 KST concurs with the comments submitted by Rotary Rocket regarding Item C.1 with the following exception:
Item I, change to read, “Passengers should have some form of redundant life support system at their disposable.”

2.0 KST concurs with the comments submitted by Pioneer Spaceplane, regarding Item C.1.

3.0 KST concurs, generally, with the comments submitted by Vela Technology regarding Item C.1.

1.3.2 Item C.2: Training and Personnel Requirements

The Working Group agrees that:

1. The existing pilot licensing framework within the FARs provides adequate guidance for RLV pilot qualification.

A.1 Comments on Item C.2 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, or possess significant flight test experience. (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.
- The pilot in command should complete a training program developed by the RLV operator.

A.2 Comments on Item C.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, we therefore recommend that:

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

Due to the experimental nature of RLV flight-test programs, we put forth further recommendations that:

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

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).

A.3 Comments on Item C.2 Submitted by Vela Technology

We take the position that crew and passengers require little, if any, real screening/training above that required by today’s airline crew/passengers. Also, in any case and under all circumstances, no certification of passengers should be done by the FAA—it is not in their charter. (These are 2nd party liability and contract matters between the carrier and the individual passengers/crew, just as with other carriers today.)

A.4 Comments on Item C.2 Submitted by Pioneer Rocketplane

1) Concerning training requirements, Pioneer believes that the existing Federal Aviation Regulation 61.31, “Type rating requirements, additional training, and authorization requirements” provides adequate guidance for RLV pilot qualification. Essentially, RLV’s should be considered “other aircraft specified by the Administrator “ for which the pilot must hold a type rating. The training required to be granted a type rating in a specific RLV should depend on the specific vehicle characteristics, as does any type rating.

2) Pioneer believes that flight test experience is prudent for many RLV test flights, but considers it unwise and unprecedented to require graduation from a test pilot school for flight test personnel. Many issues are involved here:

a) What constitutes a “recognized” school? Clearly the USAF and US Navy test pilot schools would be recognized. What about the National Test Pilot School at Mojave, CA? What about foreign test pilot schools? What about “Joe’s Corner Test Pilot School”? Is there an accreditation board for test pilot schools? No.

b) How long a course of study would be required? The organization that evolved into the National Test Pilot School used to offer a “Short Course in Flight Test Techniques”, sponsored by and held at the USAF Test Pilot School. Would this qualify?

c) The requirement for test pilots to be TPS graduates is unprecedented in commercial companies, even for aircraft receiving FAA certification. Lancair’s newly-certified Columbia 300, for example, was not flown by TPS graduates. Are all Cessna test pilots TPS graduates? I don’t think so. Consider this – the Society of Experimental Test Pilots gave a lifelong achievement award to Dave Morss for his contributions as a flight test pilot – and he is not a TPS graduate.

d) While Pioneer expects to recruit from the ranks of TPS graduates for many of its flight test pilots, we do have a company officer who has been a USAF Thunderbirds pilot and has performed more air-to-air refueling operations than any other active pilot. Surely he is qualified to participate in the air refueling testing! Is he a TPS graduate? No.

A.5 Comments on Item C.2 submitted by Kelly Space & Technology, Inc. (KST)

1.0 KST concurs with the comments submitted by TGV Rockets regarding Item C.2.

2.0 KST concurs with the comments submitted by Rotary Rocket regarding Item C.2 with the following exception:
Item iii, delete (Pilot graduation from a "recognized" test pilot school, although probably good policy, should not be a requirement.)

3.0 KST concurs with the comments submitted by Vela Technology regarding Item C.2.

4.0 KST concurs with the comments submitted by Pioneer Rocketplane regarding Item C.2**.**

5.0 It is appropriate for the command pilot to be a TPS graduate during flight tests. Pioneer Rocketplane's arguments, however, regarding TPS accreditation are quite significant, and should the "desirement" of a developer become a "requirement" mandated by the FAA, this issue would surely have to be addressed. Considering the challenge of RLV licensing facing the developer under the best of circumstances, the accreditation issue could become a real bucket of worms. KST can conceive of the possibility of TPS accreditation becoming part of the critical path in the development cycle for some developers. It would probably be in the best interest of both the FAA and the RLV industry to make TPS graduation for a test pilot optional. The existing FARs should be adequate for the purpose of pilot qualification.

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1.3.3 Item C.3: Functional Responsibility for Public Safety-Related Operations

The Working Group agrees that

1. The same framework that is used for aircraft should be applied to RLVs. Specifically, the RLV pilot-in-command has ultimate responsibility for all operational decisions, while ground personnel offer information and advice on decisions.

A.1 Comments on Item C.3 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 Human Rating Safety Standards – specifically Man-Systems Integration Standards NASA-STD-3000 Volume I and II, July 1995.

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.

A.2 Comments on Item C.3 submitted by Kelly Space & Technology, Inc. (KST)

1.0 KST concurs with the comments submitted by Rotary Rocket regarding Item C.3.

2.0 As noted in Rotary Rocket's comment, NASA reports on manned systems would be a valuable source for human rating safety information. It is important, however, that the NASA information remains only a source or database for development of guidelines for the RLV industry. Arguments presented by numerous developers during the course of preparing this report regarding the absolute necessity of the successful return of the RLV for the survival of the business provides a powerful motive for ensuring crew safety, in addition to the purely humanitarian motive. The FAA and the developers must work in concert in developing these guidelines in the same spirit that has energized the creation of this report.

PART 2

FAA Draft Interim Safety Guidance for RLV's, RLV Working Group Recommendations

WORKING GROUP GENERAL AGREEMENT ON FAA DRAFT INTERIM SAFETY GUIDANCE FOR RLV'S

1. Defining safety Guidelines for RLV's is made challenging by the diversity of vehicle configurations, flight scenarios, and capabilities. The Working Group agrees that this diversity reflects a healthy, creative industry and is not to be discouraged.

2. In light of such healthy diversity, the Working Group agrees that blanket imposition of the FAA's proposed Guidelines would be detrimental to the nascent RLV industry. Working Group agreement on this topic encompasses the following points:

   - A blanket imposition of these Guidelines would not be required to assure public safety. Indeed, such an imposition would dispose prematurely of innovative approaches to safety and risk mitigation that might advance public safety and ultimately benefit the entire industry.

   - Blanket imposition of these Guidelines would create a poorly configured licensing regime that could well overestimate the risk posed by some RLV concepts, and seriously underestimate the risk posed by others.

   - Imposing such Guidelines upon all RLV systems would force developers to adopt the safety systems which are already in place at the national ranges and which have proven to be costly and inefficient.

   - Imposing such Guidelines would eliminate the flexibility required to fairly evaluate all RLV concepts. Consequently, the regulatory environment would inadvertently and unfairly inhibit the success of entrepreneurial initiatives.

   - Such blanket Guidelines, by their very nature, would restrict developers' technical and commercial options. It could inhibit innovation, technical advancement and competition in the emerging RLV industry.

3. The Working Group agrees, therefore, that the FAA Guidelines for RLV's, which Working Group members have commented on below, now are, and ought to be, voluntary and instructive, not mandatory.

4. Working Group members agree to consult and address these Guidelines as indicative of FAA concerns as each developer prepares its own Licensing Plan under the Regulatory Framework described in Section 1 above.

2.1 Objective 1: Public Expected Casualty

"The public should not be exposed to an unreasonable risk of harm as a result of RLV operations. Risks to public safety will be measured in terms of collective risk, similar to launches from Federal ranges. The risk to the public for Reusable Launch Vehicle (RLV) operations shall not produce a total public casualty expectancy (EC) greater than that allowed by Federal ranges, that is 30x10-6 during the launch and reentry phase of a mission. This per mission EC includes both launch and reentry risks as parts of a single mission. (The launch and reentry phases of an operation together are regarded as one mission that must satisfy this EC criterion.)"

The Working group agrees that:

1. A Public Casualty Expectation analysis is one method among many, and 30x10-6 casualty expectation is one threshold among many, for assessing a system's qualification for licensing;

2. This method and this threshold may not be considered appropriate by individual developers for their system configuration and operations scenario;

3. To ensure the development of a healthy domestic RLV industry, the FAA must allow, and give serious consideration to, other methods and other types of thresholds for conducting an assessment as proposed by developers commensurate with the maturation of the industry;

4. The only way to provide the regulatory flexibility necessary to ensure the development of a healthy domestic RLV industry, is for the FAA to give serious consideration to other methods for assessing a system's qualification for licensing, and other thresholds of assessment, as presented by developers as part of their individual Licensing Plans;

5. Furthermore, the requirement that launch and landing be considered as part of the same operation for hazard analysis is overly restrictive and is likely to have significant negative impacts on RLV operations out of and into the United States.

Attachments to Objective 1 Recommendations

A.1 Comments on Objective 1 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.

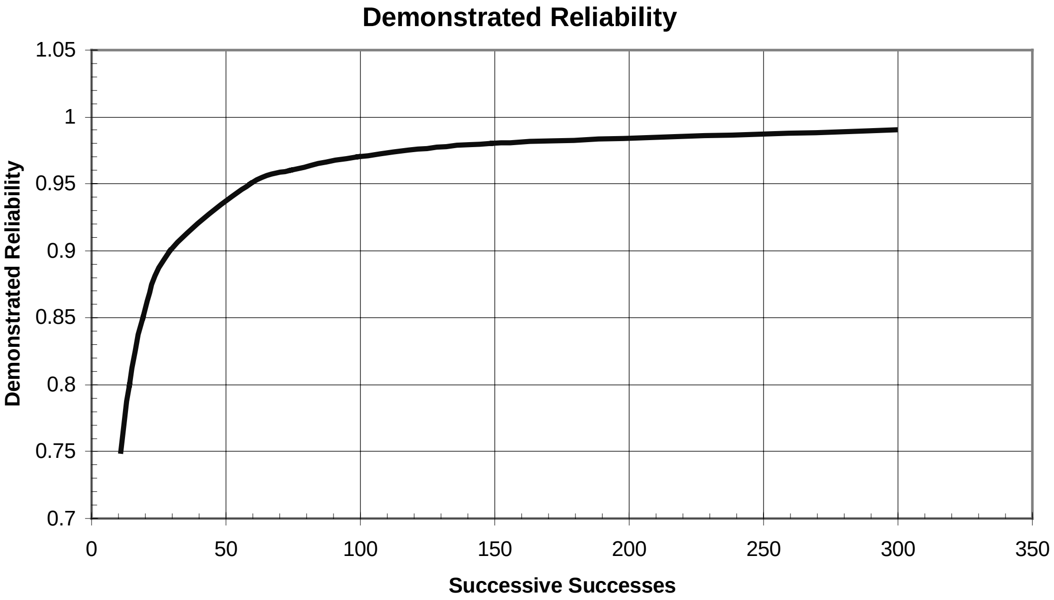

Figure 2 - Number of Tests That Must Be Performed Without Failure to Provide a Specific Minimum Reliability at a 95% Confidence Level

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.

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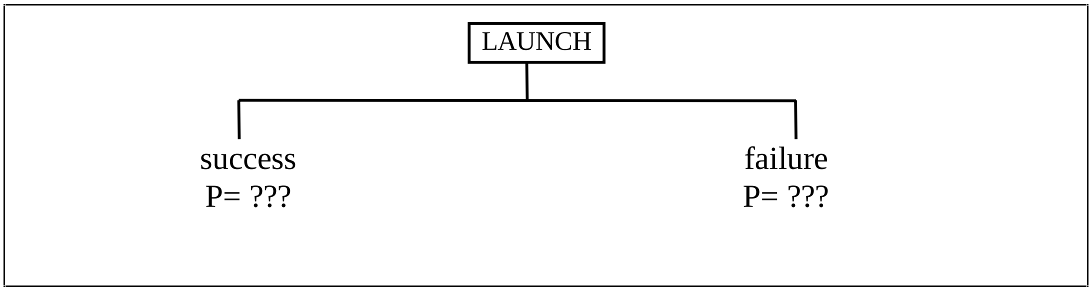

Figure 3 -Top Level Event Probability Tree for a Conventional Expendable Launch Vehicle

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 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.

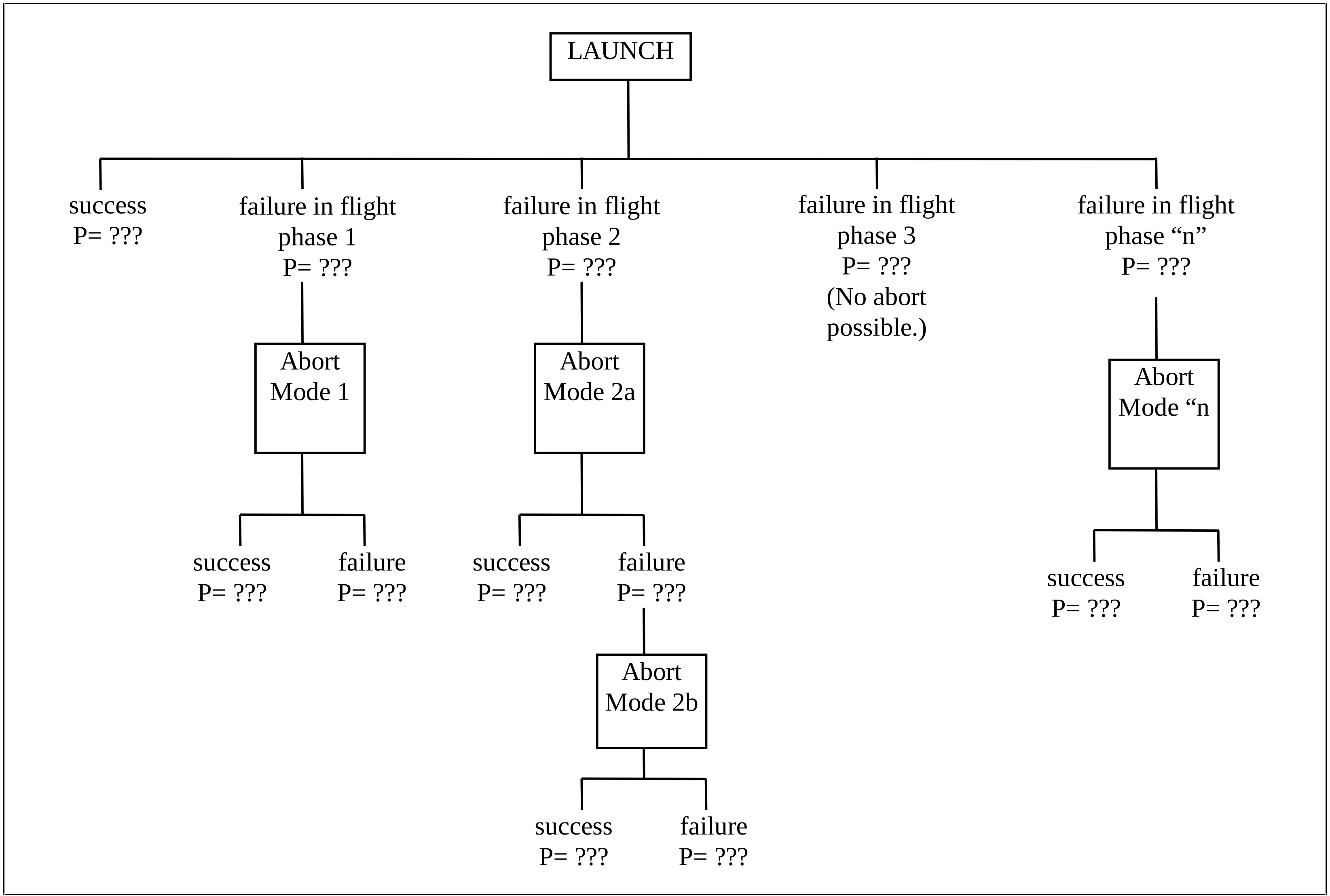

Figure 4 - Top Level Event Probability Tree for a Hypothetical Reusable Launch Vehicle

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.
4. 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.

A.2 Comments on Objective 1 Submitted by Vela Technology Development, Inc.

1) The risk to the public for Reusable Launch Vehicle (RLV) operations should not produce a total casualty expectancy (E_c) greater than that to which the public is already subjected (such as that produced by daily commercial aircraft operations). To necessarily restrict risk to that admirably obtained by the federal ranges through their limiting of overflight and the use of destruct systems would be equivalent to restricting daily aircraft operations to similar ranges and flight termination systems. An analogy in the automobile world would be to use the argument that since a speed limit of 55 mph is "safer" than something higher, then a speed limit of 0 mph is the safest of all even if impractical to normal activities. The issue is not whether we should be more risky than ELVs; but, rather, why should we necessarily set a limit less than the rest of the transportation industry.

2) If E_c is to be used as a measure of public risk, I suggest a target value be set at a level commensurate with commercial aircraft such as that of a fully loaded 747. The discussion contends that, "The RLV safety system will be required to … provide a level of public safety that is at least equivalent to the level of public safety provided by ELV safety systems." Since RLV are just the newest branch of the transportation industry, I suggest a more practical measure of public safety would be that afforded the public everyday by the rest of the transportation industry. And, while thankfully ELV have never killed a member of the public on the ground, that unfortunately cannot be said of the rest of the transportation industry.

3) The open question is how that obviously acceptable risk level compares with the level promulgated by the federal ranges for ELV operations.

4) Use of design reliability criteria are much preferable to use of E_c in an attempt to promote safety. For example, fault tolerance in various systems is much more important to system reliability than E_c will ever be. Design reliability criteria translate directly into safer designs, E_c translates into nothing with such a direct desired effect.

A.3 Comments on Objective 1 Submitted by Lockheed Martin and concurred by Kelly Space & Technology, Inc. (KST) & Scitor Corporation

The casualty expectation E_c 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 E_c 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 as 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 about 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.

Use of Casualty Expectation Analysis can be Extended into the Flight Test Phase.

Change Objective 1 as stated below:

Objective 1. "The public should not be exposed to an unreasonable risk of harm as a result of RLV operations. Risks to public safety will be measured in terms of collective risk, similar to launches from Federal ranges. The risk to the public for Reusable Launch Vehicle (RLV) operations shall not produce a total public casualty expectancy (E_c) greater than that allowed by Federal ranges, that is 30x10-6 during the launch and reentry phase of a mission. This per mission E_c includes both launch and reentry risks as parts of a single mission. (The launch and reentry phases of an operation together are regarded as one mission that must satisfy this E_c criterion.)" The calculation of E_c during the operational phase of a program shall utilize standard techniques in determining Probability of Failure (P_f) data. Standard techniques usually include the use of both analysis and test methods. Modified P_f data will be utilized during the flight test phase. Modified P_f should compensate for uncertainties associated with those aspects of the system which could not be verified using ground tests.

A.4 Comments on Objective 1 Submitted by TGV Rockets

TGV's position is that the use of E_c is neither correct nor incorrect. It exists, it is useful to some elements of industry and should be allowed to remain. TGV does not oppose the alternative licensing regimes proposed by other members of the RLV Working Group, we simply believe that these other regimes should be options rather than mandatory standards.

A.5 Comments on Objective 1 Submitted by Kelly Space & Technology, Inc. KST)

Several concerns have been articulated both pro and con regarding this metric, including the following:

1.1 Comment: Use of casualty expectation analysis for RLVs is technically unsound

This argument is based primarily upon a comparison of historical launch reliability data for ELVs with theoretical reliabilities for these systems as determined by E_c calculations, which admittedly are considered confidential and not published. Since these launch reliability figures apparently vary from about .5 to .93, it appears that there is a huge discrepancy with the $30x10^{-6}$ number specified in Objective 1. This is like comparing apples and oranges, since the Public Expected Casualty calculation addresses population density as a major parameter in the calculation. Thus, in the case of ELVs, launching over very sparsely populated areas, such as the open ocean, historically has provided public safety for third parties. For RLVs as well, this is a viable approach. Increasing reliability through the use of off-the- shelf components with demonstrated reliability is another.

1.2 Comment: Casualty Expectation Analysis for RLVs ignores the implications of reusability.

Although the current E_c calculation fails to address reusability, there is no reason that this parameter can’t be included in calculations for RLVs. It’s clear that this deficiency must be addressed and a rational approach developed for determining the impact of maintenance upon Ec. Although, as pointed out in this argument, there are those who believe that reusability decreases reliability as well as those who think that reusability increases reliability, there is certainly a rational approach to resolving this dilemma. Achieving continuing reliability, thus acceptable Ec, will undoubtedly be based upon some minimum maintenance and refurbishment requirement for each RLV concept.

1.3 Comment: Casualty Expectation Analysis for RLVs places an undue burden upon developers

Although it is true that the presence of abort capability complicates the Casualty Expectation Analysis, abort capability is certainly amenable to analysis and inclusion in the E_c calculation. Abort capability obviously will vary for each RLV concept, the greatest variation probably dependent upon whether the RLV is manned or unmanned as well as other factors. As with the parameters of reusability, it will be necessary to address a rational approach to the impact of abort capability upon the E_c calculation. Each concept will have a finite number of abort scenarios for each flight

phase, even though there will be an infinite number of impact points. It will be necessary for each concept to address the footprint of these impact points as the RLV progresses down-range and select the worst-case condition for each abort scenario. Although difficult, it is certainly feasible. For manned systems, pilot intervention introduces further flexibility to the abort sequence and further complicates the E_c calculation. Although autonomous systems may introduce flexibility as well, whether the flexibility is as great as for manned systems is problematic. In either case, however, the impact of abort scenarios is quantifiable.

1.4 Comment: Casualty Expectation Analysis for RLVs yields no relief to regulators

As noted in this argument, lack of a Flight Termination System (FTS) poses additional constraints upon regulatory personnel, requiring them to develop a more thorough understanding of the design and performance aspects of the particular concept. The question is – compared to what? In the case where the regulators merely review certain documents agreed upon between the FAA and the developer in order to establish the viability of a system prior to licensing, a level of concept knowledge is required similar to that required to evaluate a system lacking a FTS. The level of knowledge required of the regulator for the RLV without a FTS is greater only compared to that where no knowledge is required. This situation is clearly unacceptable to any regulatory regime.

1.5 KST concurs with the comment regarding Casualty Expectation Analysis for RLVs submitted by Vela Technology Development, Inc., in particular in regard to item A.2, 4) The debate between the efficacy of E_c compared to design reliability criteria won't be resolved in our lifetimes.

A.6 Comments on Objective 1 Submitted by Rotary Rocket Company

Rotary Rocket Company believes that in the short term E_c criteria can be used as a method of determining whether or not a license should be issued to an RLV operator. The suggested criteria of 30 x 10^{-6} should however be examined before it is set as a limit. Rotary Rocket Company fundamentally believes that all aerospace activities should be regulated to the same level of safety. If for example, experimental aircraft are shown to be licensed with an E_c that is less stringent (a higher E_c value) than the suggested limit, the RLV limit should be modified accordingly.

A.7 Comments on Objective 1 Submitted by ASTI

Any risk to the public should become essentially the same as "allowable risk" for aircraft over-flight of the public. The means to calculate and/or determine acceptable risk should not be cast in concrete, but should rather be allowed to develop and be modified as the nascent RLV industry matures and develops. FAA needs to ensure that any regulations, directives or the like can be modified as the industry grows.

Historically, E_c calculations were developed to ensure safety of the public primarily from unmanned weapon systems. Whatever system is adopted must be allowed to grow with the maturation of the RLV industry.

2.2 Objective 2: Safety Process Methodology

"In addition to the expected casualty objective, an applicant should apply a disciplined, systematic, and logical safety process methodology for the identification and control of hazards associated with its launch and/or reentry systems."

The Working group agrees that

1. The predictable return of the vehicle is necessary for any commercial RLV service to be viable;

2. Work accomplished to ensure the predictable return of the vehicle also contributes toward system safety, and is, in fact, a "stricter standard."

3. Depending upon system configuration, a developer may choose to emphasize efforts that address his particular design features, and place less emphasis on those that do not;

4. The imposition of a single safety process methodology on all applicants raises costs, decreases flexibility, and potentially renders the domestic RLV industry non-competitive;

5. To ensure the development of a healthy domestic RLV industry which will adequately serve the commercial market, the FAA must seriously consider any safety process methodology that the developer has employed to address the developer’s peculiar safety needs.

6. In addition, the FAA should focus on its primary responsibility, that of ensuring the safety of the general public. As such, ground operations safety, which is already regulated by county, state, and other Federal agencies should not also be regulated by the FAA.

Attachments to Objective 2 Recommendations

A.1 Comments on Objective 2 Submitted by Vela Technology Development, Inc.

1) Figure 1B equation ***Launch E_c + Reentry E_c = Mission E_c*** appears to be in error.

In Attachment 2,

$$\mathbf{E_c = \sum_{i=1}^{n} p_i C_i}$$

where,
n = the number of possible different events
p_i = the probability of the i^{th} event, and $p_1 + p_2 + \ldots + p_n = 1$
C_i = the consequence of the i^{th} event

For the equation in Figure 1B to be correct, one would have to assume (in this one simple case) that, for the mission E_c, the sum of the probabilities of all events (during Launch and Reentry) would have to be 2 (P_L=1, P_R=1; P_L+P_R=2). Since, one could also divide the mission into an arbitrarily large number of periods, one could similarly argue that the sum of probabilities would add to an equally arbitrarily large number. Therefore, if the equation in Attachment 2 applies to the entire mission, the mission E_c is **NOT** the sum of the E_c for Launch and Reentry; but, rather a number calculated on its own and covering the entire mission.

But, then, maybe the equation in Attachment 2 is wrong and the p_i do not add to 1? (see subparagraph 3 below)

Let me also suggest, if you have trouble believing from pure mathematics the fact that the mission E_c is not a sum of the Launch E_c and the Reentry E_c , then you can begin to appreciate the fallacy of using E_c in a meaningful way at all.

2) The term “event” is not used in a consistent fashion throughout the document. Sometimes it refers to a physical happening and at other times, such as in the example E_c calculation, it refers to a grouping of physical happenings with similar “consequences”. Thus, I would also like to argue that Success, Abort and Failure, as shown in the example calculations, are less “events” then they are “outcomes”. This draft document seems to group all actual physical events which might have these “outcomes” together thus providing bins against which to assess “consequences”; where, in this example, the “outcomes”—and therefore “events”—are defined by their “consequences”. Success herein is defined as the group of all physical events whose consequences are zero casualties. Thus, any user of E_c is going to be forced to define their “events” as groups of their own possible mission “outcomes” each group having similar “consequences” as you have done in your simplified example.

Using this logic, I argue, there are only two practical “events” for any RLV mission: 1) that for which the “consequences” are zero casualties, and 2) that for which the “consequences” (expected casualties) are non-zero. The combined probability of these two “events” must clearly sum to 1.0 for the entire mission (or for any other period at which one is looking). In other words, using the method described in the example, I need to know my E_c in order to calculate my E_c.

3) Consider an alternative implementation of the equation in attachment 2. If events are discrete physical possibilities, each with its own probability of occurrence during a given time frame or mission duration, then the calculation of E_c would be much different and the sum of all p_i would NOT necessarily add to one, but the average casualties from an average mission would be theoretically more accurate. This would, however, raise the specter of an infinite array of physical events, each with a probability of occurrence, making the actual calculation of E_c impossible.

Since Attachment 2 does not describe a methodology; but, rather, describes a philosophy which, I suggest, is itself, as shown, inconsistent and flawed and unless a true implementation example that can withstand examination can be provided for use in RLV safety estimation, I recommend E_c be abandoned as useful to neither public safety nor the RLV industry.

A.2 Comments on Objective 2 Submitted by TGV Rockets

TGV is very concerned about the idea of establishing regulations regarding safety process standards within new corporations. TGV believes that as long as an E_c analysis of a vehicle has been satisfied, then the safety review process should only be used in support of an alternative licensing regime.

TGV agrees with other members of the RLV Working Group in believing that designing and safety engineering for the predictable safe return of a vehicle is a "stricter standard" than those proposed by the FAA. TGV also agrees with Kistler Aerospace that "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." TGV is not opposed to safety process standards, merely the codification of these standards into unnecessary regulations.

A.3 Comments on Objective 2 Submitted by Kistler Aerospace

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, choose one type of analysis over another, and choose validation and verification methods that present a valid alternative to those historically employed in support of a Government contract.

The FAA should also recognize that ground operations safety is already regulated as an industrial activity by various range authorities, county agencies, state agencies, and other Federal agencies. There is no need for the FAA to also impose oversight of operator ground operations safety.

A.4 Comments on Objective 2 Submitted by Lockheed Martin

We assume the FAA interest in a program’s Safety Process Methodology is generated by the fact that the safety process is one of the methods used to assure the vehicle is capable of re-flight. We agree that a prudent safety program is necessary; however, the comments below illustrate the problems that can be encountered if the exact specifications are dictated by the regulatory agency. For example, the inclusion of Health Monitoring Systems as a safety critical system should be reconsidered. Only systems whose failure can effect safety of flight DURING THAT FLIGHT should be included in the Safety Critical Systems lists and hence segregated for special scrutiny. We make only re-flight decisions based on the Health Monitoring System--NO real-time in-flight decisions. If a component's performance is degrading to the point that a decision must be made during flight, and the component’s performance is detected by a transducer or combination of transducers and algorithms, then this transducer and signal processor would be part of the Redundancy Management System and IS included on the Safety Critical Systems list.

Validation of Safety Critical Systems
The use of Safety Factors (SF) is but one technique used to address a more fundamental concern...that of "confidence." We would prefer a more direct metric that reaches directly to the fundamental issue. Safety Factors can increase our level of confidence but they may, in fact, be too constraining and force the allocation of excessive resources that might provide increase safety elsewhere. In short, other techniques might be more cost effective. We would like the opportunity to exercise these other techniques when appropriate. Furthermore, we do not understand how QA records help establish design adequacy. Most QA organizations will document and assure that the processes, procedures and requirements established by the program were indeed carried out as expected. In the extreme, if the program calls out an inadequate process or test, we do not rely on the QA organization to catch the error.

A.5 Comments on Objective 2 Submitted by Universal Space Lines

For space to reach its development potential it must be routinely, safely and affordably reachable from spaceports located around the world. For this to happen a new transportation infrastructure, the Spaceways, must be put into place joining past transportation infrastructures of roadways, waterways, railways and airways all of which played a vital role in opening and expanding the frontiers here on earth.

At the heart of the Spaceways development are the national and then international regulations, procedures and protocols to govern their safe, efficient operations to open the peaceful use of space by the global community of spacefaring nations.

In planning today for the Spaceways development there are three key factors to consider: 1. Customer; 2. Safety; and, 3. Service.

1. Customer:

In laying out today's development plans for the Spaceways it is important to recognize that the customers who will use and depend on the Spaceways do not exist today. Businesses do not yet exist that require daily flights to space laboratories, factories, repair stations, refueling stations, power plants, hotels, sports arenas and hundreds of other businesses that comprise our dynamic earth bound economy. One of the world's largest industries, tourism - a four trillion dollar a year business, does not yet call space a destination for travel and fun. Tourists may lead space development and their routine travel to and from space may open the way for rapid terrestrial point-to-point travel with the development of an enormous spaceport development and operations industry.

Today, there is a very successful set of customers for space transportation in the satellite launch market - a market that is continuing to grow for commercial applications. In the next ten years as many as 1500 to 2000 satellites may be in orbit around the earth, providing a very good business opportunity for today's launch systems. International Space Station and its crews will require transportation services for crew and cargo to and from this laboratory.

In planning for the Spaceways it is very tempting to use this relatively well-defined market as the basis for projecting customer/market requirements.

Today's customers would like to see significant reductions in the price of getting their satellites to orbit and in their losses due to launch failures, (which also reduces their insurance prices). Business models built around today's customers will limit the investment made in new transportation systems that only have to successfully compete with existing systems. The end result of the current round of launch system developments may be the reduction of launch prices for a finite market and a squeeze on the launch providers for further reductions in launch price (and consequently launch profits reductions). There is nothing now that is causing the market to increase.

Furthermore, to support this limited market, the space transportation infrastructure does not have to grow appreciably beyond what it is today. The emphasis will be more on price competitiveness than on expanding space transportation services.

The danger for the nascent reusable space transportation (RST) industry is that it will build a new infrastructure and concept of operations that simply supports the present without building a basis for future expansion.

For the space frontier to reach its potential as a major new economic sector a safe, low cost, routine Spaceways infrastructure must be put into place; an infrastructure that supports hundreds then thousands of flights per year to and from and through space, an infrastructure that can help the economic expansion of space and then grow with the new demands of space travel. Effectiveness will be measured by cost per flight and availability. When a flight schedule is posted the customer wants to fly then, not when it is convenient for the Spaceplane to fly or the spaceport to support a flight. The goal must be to service the space business frontier, supporting unbounded developments. Overall architectures for the Spaceways must be developed and methods for planning, monitoring and controlling the traffic need to be developed and demonstrated.

Available and developing technology for reusable space systems can support the development of the performance and operations required for the Spaceways. It will be up to the developing RST industry to begin a new focus to assure that such operations and performance can be maintained to achieve both sustained flight safety and the promise of low cost operations and lower prices. Achieving this new capability requires an emphasis on low cost with high operational safety; reusable vehicles that can be type certified and commercially operated and maintained for years of safe, routine flight, operations that will stimulate and support future growth of the space frontier. A certification process for RST systems design and operation could provide the systematic approach for achieving this focus.

A cooperative effort by governments and the RST industry needs to begin to establish and sustain policies and projects, which specifically deal with a broad space-development objective, centered on first developing the Spaceways infrastructure. When these efforts becomes viewed as serious, it will stimulate the entrepreneurs, fully engage the public, and bring to reality the benefits of a place called space.

Therefore, as the RST industry plans today to implement the new systems, it needs to consider policies, regulations, developments and concepts of operation that will support, stimulate and satisfy the next generation customer requirements.

2. **Safety:**

One of the biggest changes that must occur in the present day planning for the future is the need to recognize safety as the main design and operating criteria for future reusable space transportation systems. Fundamental design and operational approach changes must be made from today's probabilistic launch readiness approach to a deterministic flight safety approach. This requires two key approach elements: 1) fail-safe designs and 2) maintenance that sustains the safe design. These are at the heart of the success of the aircraft and airline industries.

Processes and procedures need to be established now that will provide the public with the same assurance of safe travel to, from and through space as they presently enjoy and demand for travel through air. That air travel has come to be the safest mode of transportation while supporting a very profitable aircraft and airline industry is the result of a highly cooperative, highly interactive program between government, Federal Aviation Administration (FAA), and industry. At the core of this successful cooperation is a well defined process with experienced honed procedures providing governing boundaries of safety at every step in the design and development, production, operation and maintenance of new and existing air transportation systems.

This process sets (and updates through operational experience) the standard by which the FAA regulates industry and industry regulates itself. This process has one overarching goal - assurance and protection of public safety and safeguard of property and environment. For space travel to realize its financial potential a similar process must be put into place with a single purpose goal of ensuring public safety and the safeguarding of property and the environment. A decision to proceed with the reusable space transportation systems needed for the Spaceways commercial design, development, production and operation can only be made with an understanding of its ability to be designed and operated to meet this goal.

In reaching for this goal it is essential to recognize the distinction between system safety and reliability.

Safety deals with the consequence of failure and reliability deals with the likelihood or frequency of failure. Safety deals with lives and property; reliability deals with cost and replacement times. With the heritage that exists from the expendable launch vehicle operations it is easy to use the two terms interchangeably. The consequence of failure of an ELV subsystem or component is generally thought to be the loss of the system. Lives and property are protected through isolation of the operations. ELV experience has been that in every one hundred ELV launches from two to ten vehicles with their payloads are lost.

The implication of this type of design and operations for a RST vehicle was shown in a recent Aerospace Corporation paper (1) in which it was assumed that RST safety and reliability were the same; that is, failures lead to loss of the vehicle. Their probabilistic analysis shows that fleet sizes would have to double or triple to meet launch requirements even for today's market resulting in no improvement in costs over that which could be achieved by the best of today's ELVs.

The safety record and operations constraints achieved by ELVs are not acceptable for RSTs if RSTs are to expand the space business frontier. For RSTs to meet their promise, loss of the RST vehicle must never be a design or operations option. This leads to the fail-safe rule which must govern the design of reusable space transportation systems, just as it has for aircraft.

During any given flight, no single failure or foreseeable combinations shall prevent the continued safe flight and landing of the vehicle.

For RSTs to be an operational as well as a business success the emerging RST industry must have two priorities for design. First, design and concepts of operation of the system must provide for the safe return and landing of the vehicle together with its crew, passengers and cargo even with anomalous operations events and/or equipment malfunctions or failures, throughout the entire operations envelope.

This is the fail-safe rule that also effectively eliminates the distinction between manned and unmanned flights.

Second, the system design, manufacture and operation must incorporate both a quality and a maintenance plan that assures that the margins associated with achieving the first design priority are sustained throughout the operational life of the system. How well the RST industry will succeed in meeting these priorities will become a matter of historical record of learning experiences, which will enable the industry to continuously improve and grow. If the RST industry settles for anything less than a perfect safety record, the results will support the thesis of the referenced Aerospace Corporation analysis that RSTs are simply more expensive ELVs.

Available and developing technology for RSTs supports the achievement of the performance and operations required. A new focus is required to assure that such operations and performance can be maintained to achieve both sustained flight safety and low cost operations. For new designs to be able to realize this focus the safety margins and performance that can be achieved for structures and subsystems, as installed and as maintained over the operating lifetime of the reusable space transportation system, must be quantified and used as the basis for developing new designs and maintenance programs. This can be achieved through a certification process for reusable space transportation systems design and operation.

Although the emerging RST industry does not yet have an extensive design and operations experience base, it does have available to it a proven process in place that has guided the development and operations of the world's safest transportation system - the airlines. In 1998 615 million people flew on approximately 14 million U.S. scheduled carrier flights without a single fatality. The years of experience in design and operations leading to the attainment of the operational goal of a perfect safety record has been captured in the processes and regulations of the FAA.   These regulations provide guidance for successful design and operations, providing a checklist of what must be considered and proven but the regulations do not specify how to do it. The designer and operator must decide how best to achieve safe designs that support safe operations and then determine how to manufacture, operate and maintain them profitably.

It may be argued that such a goal is too expensive to achieve. I would argue that not to achieve this goal will make RST systems very limited in applications and, therefore, too expensive to operate.

The Commercial Space Act of 1984 and subsequent amendments empowers the Associate Administrator for Commercial Space Transportation (FAA/AST) to evaluate and license space launch and reentry operations to ensure public safety. What is needed now is an agreed-to uniform process that government and industry can cooperatively follow to routinely achieve operational safety with profitability.

As suggested, the rules regulating the safe design and operation of aircraft prescribed in
the Code of Federal Regulations (CFR) 14 for Aeronautics and Space can provide an experience based starting point for a process to certify the safety of the design and operation of the reusable space transportation systems. An initial review of the Federal Aviation Regulations (FAR) suggests that the certification requirements for new reusable space transportation systems can be developed within the existing CFR 14 FAR's. While it is desirable to proceed quickly with developing and implementing these regulations and processes that will assure the public safety and safeguard property and environment, it must be accomplished in a cooperative and evolutionary manner by government and industry. Care must also be exercised to assure that undue or impossible impediments are not set in the path of the development of a new industry. This will require the proactive leadership of FAA/AST.

Following the aviation example, FAA/AST could issue a variety of certificates and licenses following a certification process path through the system acquisition, test and operation phases. This certification process would encompass activities in the design, development, manufacturing, production, operational test and evaluation (OTE), revenue operations phases and the selection of Designated Engineering Representatives (DER's). The objective would be to initially obtain an experimental type certification to operate, maintain and support the RST system during the OTE phase and then use OTE experience and empirical data to obtain a type certificate and commercial operator's license for continued airworthiness during revenue operations.

Within this process it is possible to issue certificates for different types of operations depending on the system design and concept of operations. For example, some systems might be certified to routinely operate from designated RST ranges where some of the safety objectives are achieved through isolation from other activities. Some systems might be certified to operate from Spaceports which involve over-flights of populated areas and co-existence with air traffic. Some systems might be certified to carry passengers and cargo while others only cargo. Some systems might be certified for autonomous operations while others for piloted operations. The co-mingling of these various "type-certified" systems and operations is another challenge for FAA/AST.

The key for a successful certification process is FAA/AST's interaction and active participation with industry from program outset. Industry and FAA/AST must agree, up-front, on quantifiable/measurable certification goals and a process for achieving them. The industry design staff, FAA/AST appointed DERs and the FAA/AST representatives must work jointly to prepare and process applications, develop and approve the Certification Program Plan (CPP) with specific certification basis applicable to a type design. This joint effort must continue throughout all phases.

Because RST systems operate in speed regimes and altitudes beyond that of a subsonic and supersonic aircraft, the existing CFR 14 FARs do not cover all areas of their design, production, test and evaluation, and operations. Also, many areas of the FARs are not necessary for RST systems. FAA/AST and the RST industry have much work to do to tailor the FARs to provide a practical working document for self-regulation.

The availability of a comprehensive type certification and commercial operators licensing process for a specific type design from program outset will reduce overall program risk and enhance the likelihood of commercial financing and reduced insurance rates. It will also lead to the fielding of RST systems capable of meeting market requirements and system effectiveness parameters goal within the operational safety criteria derived from the time and service proven FARs.

The responsibilities of the FAA/AST will need to be broadened to nurture and regulate the expansion of the new Spaceways transportation infrastructure. The certification process would become a living prescription for safety and an integral part of future RST system design, test and operation. It need not be a “daunting” or expensive process, if it is incorporated from the beginning with well focused and agreed to goals. It would lead to a safe design and a system whose safety can be maintained throughout its life. It would support a new transportation infrastructure that would be perceived and accepted by the public for safe, routine travel to and from and through space from spaceports located in their communities.

The technology is in-hand to achieve the performance and operations goals for the reusable space transportation needed to open the Spaceways. A new focus is required now to assure sustained flight safety and low cost operations demanded for the commercial success of the Spaceways. The certification process, so successfully used by the aircraft and airline industries, could provide this focus as a cooperative effort among government and industry, establishing a long-term prescription for safety.

3. Service:

For space transportation to open the space frontier to the public it must become a service, not an adventure. The Spaceways must be accessible near major population centers, if space is to be integrated into the public’s daily live beyond communications and weather services. Spaceports must be able to move in from the coastal sites to in-land sites and support flights to all commercially attractive destinations, including rapid transportation to other terrestrial-spaceports as well as space-spaceports. To do this, space transportation services will have to be viewed by the public as safe and as contributors to the economic well being of the communities they serve.

Spaceports will become the hubs for new industries that will develop around access to the Spaceways for space travel and rapid point-to-point travel. Spaceport pairs will link international businesses along with business and vacation travel and rapid point-to-point travel can become a major contributor to the profitability of the transportation companies and bring new business to the communities they serve. Terrestrial-spaceports will be linked with space-spaceports providing extensions of industrial factories and laboratories operations into space. Space traffic control service will be put in place and seamlessly linked with air traffic control systems throughout the world.

If service is a goal, then the emerging reusable space transportation industry must be sensitive to the precedence and image that it is creating, as it is "growing-up”. It is essential that the public have a strong impression that space transportation is safe and a strong impression that safety is the driving goal of the emerging reusable systems along with their profitability.

To do this safety must be demonstrated in all RST operations. Government and industry, need to be able to explain to the public how widely differing approaches to reusable transportation are addressing safety and contributing to an experience base that will eventually allow operations of reusable space transportation systems in and near to their communities. There must be common goals for safety and a common process for certifying the safety of RST systems for the type of operations being carried-out. Whether operations are over water or land Ð whether landings are made with parachutes, by gliding back to land horizontally or by landing vertically like a helicopter - every time a flight takes place it is another data point for operational safety. The collective goal of the RST industry must be to establish a 100% safety record.

In planning, developing and operating the new reusable space transportation systems, consideration needs to be given to the long term type of service the Spaceways must support and strive to make the operational track records help create and support public demand. As a service, the RST industry needs to be able to operate anywhere, anytime to support major population centers.

A longer-term issue to consider as a service industry is whether or not the public would be best served by adopting another aviation model - that of separating the vehicle operating companies from the vehicle builder companies. There already is a trend toward that model with separate operating companies and subsidiaries being established within the large aerospace organizations and companies. A complete break might result in different incentives for the operating companies to broaden their range of services and new investment communities might participate. The developer/builder companies would have a more focused user customer to deal with that might provide a more predictable market.

Next Steps

The opening of the Space Business Frontier to the public is an enormous infrastructure development, with the Spaceways being the first major development that needs to be undertaken. The present ELV fleets together with the Space Shuttle have and will continue to provide a solid foundation of support for the presently constituted space business. New RST systems will be required to establish the safe, routine, affordable Spaceways infrastructure required to expand the Space Business Frontier by opening it to the public. The development of these new systems today must take into consideration the customers and service they will need to provide for tomorrow. A key factor in their development must be the one overarching goal - assurance and protection of public safety. It is the unrelenting pursuit of this goal that has helped to make the aircraft and airline industry financially successful for it achieved what today’s fledgling launch industry calls reusability. For the reusable space transportation industry and the Spaceways to realize their service and financial potential a similar process must be put into place with a single purpose goal of ensuring public safety.

For space development to succeed economically it must have successful commercial ventures, but in addition there also are crucial roles that government can undertake in order to insure its continued success. These roles include establishing an inclusive space policy and a supportive, nurturing environment for a broad set of space development activities. The government must assist in establishing the space transportation infrastructure to initiate and sustain the development of commercial space by the Public. The government has many ways in which it can use its federal resources to assist new programs for the benefit of the public. Two key ones are (1) its regulatory powers, and (2) its purchasing power to stimulate new ventures; both should be used.

Summary

For the expanded commercial use of space to succeed a Public Space Transportation Infrastructure, the Spaceways, must be put into place. Government and industry have essential roles in the creation, regulation, nurturing, and control of this new transportation infrastructure. For the government to take on this long-term commitment it must be part of a long-term, public-inclusive policy. Similarly, industry must take-on the development of the reusable space transportation systems with safety and price goals which will enable the general public to develop and expand the full economic potential of the space business frontier.

Reference:

1. Book, Stephen A., The Aerospace Corporation; “Inventory Requirements for Reusable Launch Vehicles”; Space Technology and Applications International Forum (STAIF 99), Albuquerque, New Mexico, February 1999

A.6 Comments on Objective 2 Submitted by Rotary Rocket Company

- Interim Safety Guidance for Reusable Launch Vehicles, page 10, Flight Tests – 3rd Paragraph:

  When an RLV flight test program takes the step towards its first orbital flight, the vehicle will have to fly such that the instantaneous impact point crosses over populated areas. There is no way to get to orbit without doing so.

- Flight test and transition to regular operations:

  Rotary Rocket Company suggests that any RLV flight be licensed if the operational regime of the flight satisfies the Ec criteria.

A.7 Comments on Objective 2 Submitted by ASTI

Is such a system, as described in this objective, meant for each launch/flight of an RLV or as with aircraft for a class/type of vehicle? Part of the system development process should also be tied to an individual system's operational concept. Some may be single stage systems, others two stage with sub-orbital and orbital components, some are all rocket powered, others are rocket and air breathing combinations, some may carry people while others are being designed strictly for "cargo hauling".

2.3 Objective 3: Human Intervention Capability During the Ascent To Orbit Phase for Orbital Missions, and throughout the entire mission (ascent and descent), for Sub-orbital Launches of Reusable Launch Vehicles

" Risks to the public from non-nominal launches should be mitigated through control based on human decision making or intervention in addition to any on-board automatic abort system. The specific flight safety systems design involving ground, airborne or on-board capability should assure the redundant ability to initiate a safe abort of a malfunctioning RLV."

The Working group agrees that:

1. Risks to the public from non-nominal launches should be mitigated;

2. Ground-based man-in-the-loop abort initiation systems, pilot-in-the-loop systems, and onboard autonomous systems can be made equally effective and reliable;

3. Each developer must determine, for his concept, the most expeditious way to initiate abort sequences in the interest of public safety;

4. The imposition of a human intervention requirement precludes the innovative use of technology to accomplish safety goals, and, in fact, removes any motivation for further developing autonomous systems for such purposes;

5. The imposition of a redundant ability requirement ignores the variability in RLV configurations and operating scenarios which could enable some systems to effectively and reliably meet safety goals without redundancy.

Attachments to Objective 3 Recommendations

A.1 Comments on Objective 3 Submitted by Kistler Aerospace

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

Objective 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. In addition, the majority of failed ELV launches from the national ranges were terminated by the autonomous on-board Flight Termination System before the human operator could even respond to the failure.

In recent public comments[2], Col. Phillip Benjamin, Commander of the 45th Space Wing Operations Group, stated that while he felt that autonomous abort systems would be required to prove themselves further, they showed the potential for reducing the need for range services and, consequently, reducing launch costs. Col. Phillips stated that he could see autonomous systems coming on in three years or so.

In the same venue, Edward O'Connor, Executive Director of Spaceport Florida, stated that autonomous abort systems would bring much greater flexibility to the ranges and make routine access to space affordable. O'Connor mentioned that we have achieved a level of robustness in electronics that makes such systems acceptable. He anticipated their appearance within two years.

The FAA should not promulgate regulations that discourage the development of systems that are seen by senior industry members as necessary for reducing launch costs and that are seen as on the verge of fruition.

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[2] FAA/AST Forecast Conference, Feb 9, 1999, Panel 3: Changing Roles and Responsibilities at the Launch Ranges

A.2 Comments on Objective 3 Submitted by Vela Technology Development Incorporated

1) The discussion contends that, “The RLV safety system will be required to provide a level of public safety that is at least equivalent to the level of public safety provided by ELV safety systems.” Since RLV are just the newest branch of the transportation industry, I suggest a more practical measure of public safety would be that afforded the public everyday by the rest of the transportation industry. And, while thankfully ELV have never killed a member of the public on the ground, that unfortunately cannot be said of the rest of the transportation industry.

   The risk to the public for Reusable Launch Vehicle (RLV) operations should not produce a total casualty expectancy (E_c) greater than that to which the public is already subjected (such as that produced by daily commercial aircraft operations). To necessarily restrict risk to that admirably obtained by the federal ranges through their limiting of overflight and the use of destruct systems would be equivalent to restricting daily aircraft operations to similar ranges and flight termination systems. An analogy in the automobile world would be to use the argument that since a speed limit of 55 mph is “safer” than something higher, then a speed limit of 0 mph is the safest of all even if impractical to normal activities. The issue is not whether we should be more risky than ELVs; but, rather, why should we necessarily set a limit less than the rest of the transportation industry.

2) Requiring human intervention may be necessary during flight testing during that portion of the flight path where having control is worthwhile; however, if other safety requirements are met, it is not obvious why human intervention should be necessarily required thereafter.

   Cruise missile testing provides a concrete example of flight tests conducted over populated (though perhaps not “heavily” populated) areas without human intervention capability (and some of these crashed too).
   See also comments under the next objective for further arguments about why human intervention throughout sub-orbital flights should not be required; it isn’t even possible.

A.3 Comments on Objective 3 Submitted by Kelly Space & Technology, Inc. (KST)

1.0 KST concurs with the comments regarding Objective 3 submitted by Kistler Aerospace.

2.0 KST concurs with comment A.2, 2) regarding Objective 3 submitted by Vela Technology Development, Inc.

A.4 Comments on Objective 3 Submitted by Rotary Rocket Company

Rotary Rocket Company concurs with this recommendation. The Roton will have pilots on board to monitor the automatic systems and intervene if any type of system failure occurs. Monitoring of automatic systems and having the capability to intervene if a failure occurs reduces operational risk.

Putting in place training programs for pilots and designing in safety mechanisms should mitigate failures that are the result of human intervention. In terms of training requirements for the crew and other human rating safety standard recommendations, please refer to our response to this issue in the section responding to Human Rating Safety Standards.

A.5 Comments on Objective 3 Submitted by ASTI

A redundant human intervention system would not necessarily preclude innovative uses of technology. In a manned/crewed system, that redundancy already exists, while in unmanned systems a “flight manager” could be used to initiate certain procedures. That basic approach was used during the DC-X/XA flight tests, and quite successfully.

2.4 Objective 4: Positive Human Initiation of Reentry Activities

"Risks to the public from non-nominal re-entries should be mitigated through control based on human enable of the reentry activity. This objective is intended to provide fail-safe assurance that reentry activities cannot be initiated prior to human verification that all pre-reentry readiness activities, including verifying the configuration and status of reentry safety critical systems."

The Working group agrees that

1. Risks to the public from non-nominal re-entries should be mitigated;

2. Ground-based man-in-the-loop initiation systems, pilot-in-the-loop systems, and onboard autonomous systems can be made equally effective and reliable;

3. Each developer must determine, for his concept, the most expeditious way to initiate reentry sequences;

4. It is not unreasonable to assume that in the future such items as weather updates and air traffic information, items which the FAA has identified as requiring human operators, will be provided through automatic systems;

5. The FAA should not promulgate rules that preclude in advance the development of such systems.

Attachments to Objective 4 Recommendations

A.1 Comments on Objective 4 Submitted by Vela Technology Development, Inc.

1) Re-entry will inevitably occur sooner or later with or without positive human intervention. So, there is no such thing as "fail-safe assurance" in the case of reentry. At best one would be able to influence near nominal reentry activities. Those reentry activities that are seriously off-nominal probably will fail-return (not fail-safe) (if not immediately, then inevitably) with or without human intervention. Such are the laws of physics. But then, when aircraft fail, they too return to earth. And, even when ELV succeed, they too return to earth in an uncontrolled fashion.

   The first issue is whether or not the "reentry corridor" is clear enough to give "clearance to land" (or more likely, clearance to enter or pass through controlled air space) and how far ahead of the reentry event, nominal or otherwise, can this clearance be given. Once the reentry sequence has begun, barring failure, a controlled reentry is inevitable. From the time "reentry clearance" can be given, the "inevitable" reentry sequence can be initiated. It could happen, and must when sub-orbital missions are flown, that "reentry" clearance will be given at "launch" and no further human intervention is required.

   Secondly, especially in the case of sub-orbital missions, having human intervention capability (e.g., having a pilot on board, having an up/downlink with a controller on the ground, etc.) does NOT mean necessarily having the ability to greatly influence the inevitability of the flight path once launch is initiated. In these cases, during that portion of the flight path that is "inevitable", having or not having human intervention capability is irrelevant.

2) By extension, any requirement for positive reentry control on an RLV must necessarily be applied to any potentially reentering ELV hardware or cargo as well. Therefore, as a minimum, all "orbiting" ELV upper stages (and sub-orbital ELV's as well) must have positive human intervention capability for reentry control before they will be licensed for launch. What must be done, in the name of safety, in one arena, must surely be equally necessary, in the name of safety, in the other (after all, these are "nominal" ELV reentry events).

A.2 Comments on Objective 4 Submitted by Kistler Aerospace

Objective 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.

The discussion attached to Objective 4 states that items such as weather updates and air traffic coordination will require human verification. However, it is not unreasonable to anticipate that such functions as weather updates and air traffic information will soon be provided in an automatic fashion. The FAA should not promulgate rules that preclude in advance the development of such systems.

A.3 Comments on Objective 4 Submitted by TGV Rockets

This objective does not apply to sub-orbital launches because reentry is not initiated and cannot be stopped. Reentry is the inevitable conclusion to a sub-orbital trajectory.

A.4 Comments on Objective 4 Submitted by Lockheed Martin

In the event of communications failure, a pre-programmed / preplanned re-entry might be safer than a random, uncontrolled decay. This requirement is overly restrictive and will not provide the intended purpose.

A.5 Comments on Objective 4 Submitted by Kelly Space & Technology, Inc. (KST)

Public safety is of paramount importance in RLV operations. Risks to the public from non-nominal reentries should be mitigated in a manner that is both safe and cost-effective for the developer. If the mitigation approach fails to meet these criteria, there is the adverse affect of both public endangerment and failure to realize the advantages of low cost access to space afforded by RLV's.

Although on-board autonomous systems can be made equally effective and reliable to ground-based man-in-the-loop reentry initiation systems and pilot-in-the-loop systems, KST considers human initiation of the reentry sequence is currently the lowest risk approach.

Each developer should propose to the AST a reentry initiation approach that ensures public safety while enabling the developer to capitalize on the unique operational characteristics of the developer's concept.

While it is not unreasonable to assume that various off-board reentry parameters will be automated in the future, KST plans initially to utilize support services that currently exist while maintaining the flexibility to incorporate future enhancements to these systems.

The prudent approach for the FAA is to promulgate RLV regulations in such a manner to ensure public safety while encouraging creativity within the development community.

Requirements for positive control of reentry imposed upon RLVs should be similar to those imposed upon ELVs, using Casualty Expectation Analysis or other acceptable methods. Logic dictates that if reentry controls are imposed upon RLV's, similar controls must be levied upon the reentry of ELVs or portions thereof.

A.6 Comments on Objective 4 Submitted by Rotary Rocket Company

Rotary Rocket Company concurs with this recommendation. Human initiation of reentry reduces risk by allowing a complete verification of all conditions before the process has begun.

A.7 Comments on Objective 4 Submitted by ASTI

This objective appears to be concerned primarily with RLV systems that attain orbit and then reenter. The FAA must also consider two stage systems in which the first stage could be essentially a “ballistic” vehicle with very short flight times.

2.5 Objective 5: Flight Data Monitoring and Recording

The RLV and ground support systems should provide for sufficient flight data monitoring such that the status of key systems is provided during the entire launch phase of the mission and at the other safety critical mission decision points. This may be done through telemetry, in real time, to a control center which has command capability and decision making responsibility. Other data that is not essential to be monitored in real time but for which monitoring or verification is necessary for system validation, system reuse, performance characterization, etc., could be recorded onboard for non-real time download or retrieval post-mission.

The Working group agrees that

1. The assemblage of flight data serves three primary functions; accident investigation, system validation, and command and control;

2. Real time data download is necessary for, and only for, data relevant to an accident investigation in the absence of a “black box;”

3. System validation data may be recorded for later retrieval;

4. Command and control capability may reside in ground control centers, on-board system software or human pilot;

5. FAA should not adopt guidelines which assume that technology will forever limit RLV's to ground control systems, and, consequently, should not mandate that command and control data be downloaded;

Attachments to Objective 5 Recommendations

A.1 Comments on Objective 5 Submitted by Kistler Aerospace

The transmission of real-time flight-critical monitoring information is necessary in the event a failure needs to be understood in an accident analysis. However, the FAA should not assume that technology will forever limit RLV's to ground control systems, and, consequently, should not mandate that command and control data be downloaded. Appropriate mission rules followed by a ground controller will yield the same result when followed by system software or a human pilot.

A.2 Comments on Objective 5 Submitted by TGV Rockets

Many different designs for RLVs have been proposed. Many more will be proposed. Some of these proposals are for fully autonomous, piloted vehicles designed to operate much like commercial aircraft. As such, control centers with command capability and decision-making responsibility are neither required nor desired. Thus, it would seem that objective 5 should be rewritten to take these proposed vehicles into account.

A.3 Comments on Objective 5 Submitted by Rotary Rocket Company

Rotary Rocket Company recommends that you make the following change to the description of this objective.

> "This may be done through telemetry, in real time, to a control center **or through cockpit displays direct to the pilot in command, either of** which has command capability and decision making responsibility."

Rotary Rocket Company would also recommend that the list of specific information and data that need to be made available to the human operator, should be determined only by the need to support the Ec estimation for the vehicle and its operational or flight test scenario. All other data and information needs should be at the discretion of the developer.

A.4 Comments on Objective 5 Submitted by ASTI

Most of the comments previously provided appear acceptable. However, is this objective meant for both “crewed” and “remotely crewed/autonomous” systems? In the latter case, there is the very real possibility that real time data will be used also for flight-control and flight-following data, not just for post-flight or post-accident analysis.

2.6 Objective 6: Non-nominal Reentry Risk Mitigation

"RLVs designed to re-enter from orbit and survive substantially intact should not produce a total public casualty expectancy (E_C) greater than $30x10^{-6}$ as a result of nominal or non-nominal launch and reentry operations."

The Working group agrees that:

1. A Public Casualty Expectation analysis is one method among many, and 30x10-6 casualty expectation is one threshold among many, for assessing a system's qualification for licensing;
2. This method and this threshold may not be considered appropriate by individual developers for their system configuration and operating scenario;
3. To ensure the development of a healthy domestic RLV industry, the FAA must consider other methods and other types of thresholds for conducting an assessment commensurate with the maturation of the industry;
4. The only way to provide the regulatory flexibility necessary to ensure the development of a healthy domestic RLV industry, is for the FAA to give serious consideration to other methods for assessing a system's qualification for licensing, and other thresholds of assessment, as presented by developers as part of their individual Licensing Plans;
5. In addition, this Guideline appears to be redundant with Objectives 1 and 2. While Objective 6 is intended to cover non-nominal re-entry events, these same events must already be taken into account in Objectives 1 and 2.
6. Furthermore, the FAA should not impose the requirement that a malfunctioning vehicle be capable of targeting an area of open ocean or of achieving "assured breakup" as proposed in the FAA discussion accompanying the publication of this Guideline. This requirement is not imposed upon aircraft and, consequently, it cannot be justified for RLV's.

Attachments to Objective 6 Recommendations

A.1 Comments on Objective 6 Submitted by Kistler Aerospace

Objective 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.

In addition, since no requirement for "ditching" or assured breakup is imposed upon aircraft, it is difficult to understand how such a requirement could be justified for RLV's.

Regarding the requirement for conducting a Casualty Expectation analysis as opposed to some other type of risk analysis, please refer to the Attachment to Objective 1 which argues for flexibility from the FAA.

A.2 Comments on Objective 6 Submitted by Vela Technology Development, Inc.

1) Objective 6 is redundant to Objective 1.

2) ELV hardware and cargo, while not necessarily designed to survive reentry, do reenter and often reach the earth. Is this requirement also levied on ELV systems?

3) This objective presupposes a non-nominal (read catastrophic-you mention ensuring vehicle destruction before ground impact) mission failure. Such failures also happen to aircraft. No ELV today, nor any RLV currently under design, if it were to fail in a fashion presupposed under this objective, is likely to cause the public as much harm as a single fully loaded 747 in a similar circumstance. Yet, aircraft are not required to meet this type of objective. In these circumstances, we hope the hardware is designed for the maximum chance of survival for both ground and onboard personnel. Unfortunately, in the aircraft case, we know empirically that in many cases survival is unlikely. We have yet to determine if that is also likely to be the case with RLV hardware during a non-nominal reentry.

A.3 Comments on Objective 6 Submitted by Kelly Space & Technology, Inc. (KST)

1.0 Although Public Expectation of Casualty is but one method for assessing a
system's qualification for licensing, this approach has gained wide acceptance among the launch and flight test community and is quantifiable. It is true that arguments can be advanced regarding the value of such a number, however it has proven adequate for providing public safety assurance pending the generation of sufficient operational data to develop a statistically significant data base.

Although this method may not be appropriate for all system configurations, it is possible that other demonstration methods may necessitate such a large flight test sample size to develop a statistically significant database as to be cost-prohibitive for the developer. It is important for this fledgling industry, however, that the FAA provide sufficient regulatory flexibility to encompass many RLV concepts and configurations.

The Working Group agreement makes note of the fact that Objective 6 is redundant to Objectives 1 and 2. Eliminating redundancy among objectives is essential to ensuring a regulatory environment that is concise and understandable to all participants. As mentioned many times in RLV Working Group meetings and written communications, one of the most important aspects of a regulatory framework is that the developer must have the assurance that once there has been agreement between the FAA and the developer regarding that framework, licensing approval is assured when the requirements initially agreed upon have been fulfilled.

Lastly, it is important that the FAA not impose upon RLV's requirements that are more stringent than those imposed upon either aircraft or ELV's. Such an approach could kill this industry in its infancy.

A.4 Comments on Objective 6 Submitted by Rotary Rocket Company

Rotary Rocket Company believes this objective is redundant with Objective 1. The probability of non-nominal re-entries already is incorporated into the overall E_c estimation for a vehicle and its proposed operational scenario. We do not believe it needs to be highlighted as a separate item.

2.7 Objective 7: Over-flight of Populated Areas

"RLV flight over land corridors should be selected such that any land over-flight avoids densely populated areas. Determinations of population densities for such areas are based on a density that is dependent on the casualty area from each RLV configuration, and may differ for each case."

The Working group agrees that:

1. Objective 7 is redundant in light of Objective 1, and it gives the FAA arbitrary and capricious power to reject a license application.

2. Across the board restrictions on over-flight of densely populated areas implies that RLVs are forever inherently “experimental" and therefore hazardous;

3. In order for the RLV industry to reach its full potential in the United States, restrictions on the over-flight of populated areas need to be eliminated for operational RLV’s in accordance with the Licensing Plan established between the FAA and the developer for the developer’s system;

Attachments to Objective 7 Recommendations

A.1 Comments on Objective 7 Submitted by Vela Technology Development, Inc.

1) RLVs by their very nature are no more “experimental” than any other vehicle that has never flown before. As soon as experience is gained, the “experimental” moniker needs to be dropped. Across the board restrictions on overflight of densely populated areas, based on some notion that RLVs are forever inherently “experimental” (read dangerous) need to be lifted for operational vehicles following successful flight test demonstration.

2) The issue during experimental flight test (or any time for that matter) is potential impact area, not overflight area. It is not overflying that raises the potential for risk; but, rather the possibility of impacting in a given area. There should be NO overflight restrictions on an area that is not at risk of potential impact (e.g., when the trajectory heading and/or energy are such that when overflying the area any mishap would result in no debris landing in the area.) Similarly, if restrictions are to be applied, they should be against trajectories (vector & energy) that place areas along a potential fall zone at risk regardless of planned or actual overflight.

A.2 Comments on Objective 7 Submitted by Kistler Aerospace

This item gives the FAA arbitrary veto power over a launch license. It implies that even if an applicant conducts a casualty expectation analysis (as stated in Objective 1), and even if that analysis results in a casualty expectation less than 30E-6 (as stated in Objective 1), the FAA may still rule out launch on a given azimuth based upon the location of a populated area.

In addition, the existence of Objective 7 implies that the FAA itself does not feel that a casualty expectation analysis adequately approximates the risk posed by launch vehicle operations. If Objective 7 is in place, then what is the purpose of Objective 1? If Objective 1 is in place, then what is the purpose of Objective 7?

A.3 Comments on Objective 7 Submitted by Lockheed Martin

We must have an objective, verifiable metric to determine acceptability of over-flight corridors. A clear and predictable process will facilitate selection of launch site location. Recommend using Ec. See note in Flight Test section for a discussion on potential methods to increase confidence during the early flight test phase.

Eliminate this requirment. It is redundant with Objective 1.

A.4 Comments on Objective 7 Submitted by Kelly Space & Technology, Inc. (KST)

Redundancy among objectives must be eliminated as noted in KST's comments to Objective 6. Overflight of Populated Areas is addressed in the E_c calculation. When an acceptable E_c is established for a specific trajectory, overflight of the particular area is acceptable by definition. Also, as noted in comments by Vela Technology Development, Inc., the key factor in evaluating a particular launch or landing trajectory is not overflight, but projected impact area. This parameter is one of several addressed in the E_c calculation and is just one more illustration of the redundancy of this objective.

Vela Technology Development, Inc. also comments regarding the appellation of "experimental" for RLV's. The "experimental" nature of an RLV is no different from that of an aircraft and ELV. Certainly, the RLV is "experimental" during the development phase, as are aircraft and ELV's. The duration of the "experimental" designation is another parameter that must be addressed in the Licensing Plan established between the FAA and the developer for the developer's system.

A.5 Comments on Objective 7 Submitted by Rotary Rocket Company

Rotary Rocket Company believes this objective is redundant with Objective 1. If the operational scenario of an RLV is such that it overflies a populated area and the vehicle’s Ec estimation meets the accepted criteria, there is no reason to have this extra requirement. In addition, Objective 7 completely lacks any actual objective standard, such as a definition for what “densely populated” means, and it lacks any recognition that dwell time over an area is an extremely important variable in the degree of risk anyone on the ground may face.

A.6 Comments on Objective 7 Submitted by ASTI

As RLV systems prove their reliability, this objective should not preclude flight over populated areas. In addition, it is not clear that this objective is meant for just the non-orbital operations such as departure and arrival from spaceports. On the orbital operations side, does the FAA currently prevent satellite operators from flying their systems over population centers?

2.8 Objective 8: Reentry/Landing Site Risks

" The public located in proximate vicinity to the planned reentry site should not be exposed to an unreasonable risk as a result of RLV operations. For nominal missions, the predicted 3-sigma dispersion of a RLV reentry vehicle during descent (landing) operations will be wholly contained within the planned landing site. Additionally, it is a goal that the risks to the public from such a nominal reentry shall not exceed an E_C of 1×10^{-6} for areas surrounding the site."

The Working group agrees that

1. Objective 8 contradicts Objective 1 by arbitrarily allocating risk and eliminating any flexibility implied by Objective 1.

2. Objective 8 requires that the developer perform a casualty expectation analysis, further limiting the flexibility afforded by the developer's licensing agreement.

Attachments to Objective 8 Recommendations

A.1 Comments on Objective 8 Submitted by Kistler Aerospace

The material accompanying Objective 1 states that the 30E-6 risk may be allocated in any fashion between ascent and re-entry events. Objective 8 contradicts this statement and eliminates any flexibility it implied.

In addition, 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.

A.2 Comments on Objective 8 Submitted by Vela Technologies

1) The term(s) “reentry/landing site” should explicitly include the “reentry corridor/box” along/within which the RLV reenters controlled airspace. Knowing before hand the 3-σ dispersion along such a corridor/box in time and space will be necessary to safely control flight.

2) For nominal flights of vehicles which are under nominal control during landing (for which 3-σ is an extremely small, if not meaningless, figure) this objective has no meaning beyond that of requiring RLV to land nominally only at approved landing facilities.

3) All spaceports (RLV launch/landing facilities/locations) should be categorized and themselves licensed based on their capabilities to support various RLV hardware requirements (ability to support landing dispersions, controlled or uncontrolled, being just one such requirement).

4) By the requirement for E_c, to be $1E^{-6}$, is it meant that that the landing phase should contribute no more than $1E^{-6}$ to the overall mission requirement E_c? If not, then if E_c must be used at all, it should be calculated for the entire mission not just a piece. After all, why should the landing site be afforded more protection than anywhere else in the “flight path”?

5) The idea that an E_c is calculated for an area instead of for a mission or even a mission phase is to reject the E_c equation provided in Objective 2.

A.3 Comments on Objective 8 Submitted by Lockheed Martin

Eliminate this requirment. It is redundant with Objective 1.

A.4 Comments on Objective 8 Submitted by Kelly Space & Technology, Inc. (KST)

Objective 8 contradicts Objective 1 by essentially allocating risk between the various segments whereas Objective 1 specifies a combined risk for the entire mission. Although stated in terms of a goal, there is little question that the regulating agency must deal with this as a requirement. What does the regulator do if the developer's analysis, or AST's analysis, indicates a reentry/landing risk greater than the ”goal” of 1 X 10^{-6}, yet the combined risk is less than 30 X 10^{-6}? Is the license denied? The entire area of risk must be addressed to develop criteria that are both reasonable and consistent.

The document ”Hazard Analysis of Commercial Space Transportation”, revised 10-2-95, addresses ELV's only. In this document, the only reentry hazards addressed are from uncontrolled reentry of orbiting objects. It is recognized that the various RLV concepts differ greatly in both launch and reentry approaches. It appears that the preferred approach would be to address the uniqueness of each concept and combine the casualty expectation from each mission phase to obtain the total casualty expectation for that concept rather than impose an arbitrary allocation for a particular phase upon all concepts.

A.5 Comments on Objective 8 Submitted by Rotary Rocket Company

Rotary Rocket Company believes this objective is redundant with Objective 1. If the operational scenario of an RLV is such that it meets the Ec criteria set forth in Objective 1 this should be adequate. In addition, the wording is too vague to be of guidance to RLV developers, as in the requirement to calculate a more stringent Ec for “areas” of undefined size surrounding a site. Likewise, the requirement that the dispersion of a vehicle during descent be contained wholly within the landing site is without utility, since descent starts with the first de-orbit burn and thus variances from the nominal could start at a point where the resulting actual landing point is a continent away from the intended point.

2.9 Objective 9: Preplanned, Pre-approved Staging Impact Points, Contingency Landing Sites and Contingency Abort Sites

" For launch and reentry operations, RLV operators would provide staging impact points and, at selected points along its over-flight corridor, safe, pre-planned, pre-approved contingency abort landing sites. These sites must be large enough to ensure that all RLV landing hazards are contained within the designated site. There should be a sufficient number and distribution of such sites to assure abort to these sites (or to orbit) can be achieved from any phase of the flight. These sites should avoid air traffic routes or mitigation measures could be taken to ensure there are no aircraft over the site at the time of reentry."

The Working group agrees that:

1) As with commercial aircraft, it is prudent to identify abort landing sites along the intended route and within the capabilities of the vehicle under various contingencies;

2) As with commercial aircraft, however, it is unreasonable to assume that the vehicle will be able to reach an identified abort landing site under any and all possible contingencies. (Here the Working Group notes that if this were the case for commercial aircraft, no commercial aircraft would ever experience ground contact outside an airport.);

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3) A plan of action shall be specified in the event of an abort at any time along the vehicle's ascent and descent trajectory.

4) The plan of action shall not expose other air traffic to undue risk of a mid-air collision. This will be accomplished through coordination with Air Traffic Control.

5) If the requirement manifested in Objective 9 were to be imposed on the RLV industry, it would pose a significant obstacle to the development of an RLV industry in the United States.

6) To require that abort landing sites avoid air traffic routes is unreasonable, would severely restrict the azimuths to which a vehicle may fly, and would render RLV operations economically not viable in the United States;

7) This requirement is tantamount to requiring that commercial aircraft avoid flying over each other's alternative airfields;

8) To require that airspace over abort landing sites be cleared before launch is unreasonable, would pose significant obstacles to the smooth integration of air and space traffic, and would pit the powerful commercial aviation industry against the infant RLV industry;

9) This requirement is tantamount to requiring that all of a commercial aircraft's alternative fields be cleared before that aircraft is permitted to take off.

Attachments to Objective 9 Recommendations

A.1 Comments on Objective 9 Submitted by Vela Technologies

Based upon verbal remarks made by the FAA personnel at the 11 February 1999 public meeting on this document, this objective does not refer to, nor does it require the pre-identification of, "emergency" landing sites; rather, these would fall under the category of "any cornfield in an emergency". It does refer to those "contingency" sites that an operator might expect to have to use under non-nominal, but non-emergency conditions.

1) Given the infrequency (especially post flight-test) of which any such site might be exercised, this objective drives the RLV operator to NOT specify any such ground sites (anything non-nominal requiring landing/return would be a declared emergency) unless:
   a) to do so does not necessitate environmental assessment of each such possible site by the RLV developer; and/or
   b) numerous potential (alternative spaceport) sites are already categorized by the FAA (as potential "alternative" runways are currently).
2) Consideration should be given to expanding the idea behind this objective to address the alternative "reentry/return corridors" that may be needed under certain circumstances in addition to simply the final landing sites. Since these "corridors" are likely to be dynamic, it is more likely to consider imposing a process for controlling traffic in these corridors than it is to require their definition in detail (and clearing) before hand.
3) It should be recognized that (unlike ELVs) RLV may not have to establish exclusion zones for aircraft. Some RLV systems will be able to operate quite comfortably within existing air traffic control systems for part, if not all, of their atmospheric flight and requiring other aircraft to "keep out" takes on a meaning considerably different from that of an ELV launch.
4) When an RLV files a flight plan, it could look very much like an aircraft flight plan of today. It should not be the result of this document to require a difference when none is needed.

A.2 Comments on Objective 9 Submitted by Kistler Aerospace

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. Air traffic over the North Atlantic is not halted for launches out of Cape Canaveral, nor are flight operations at Los Angeles International Airport (LAX) subject to the launch schedule at Vandenberg AFB.

These requirements will either restrict RLV's to operating between air routes and, indeed, individual flights, or force air traffic to re-route and/or delay flights to accommodate RLV operations. The first will render RLV operations out of the United States unviable. The second will incite the air transport industry to oppose RLV operations, and essentially confine RLV operations to established national ranges.

A.3 Comments on Objective 9 Submitted by Kelly Space & Technology, Inc. (KST)

1.0 KST concurs with the comments submitted by Vela Technologies.

2.0 KST concurs with the comments submitted by Kistler Aerospace.

3.0 The FAA regulations, as emphasized in many communications, must recognize the uniqueness of the various RLV concepts in order to make RLV operations within the United States viable. These concepts use various modes of vertical and horizontal takeoff as well as various modes of vertical and horizontal landing. Some concepts propose the use of commercial airports while others propose the use of specially-prepared takeoff and landing sites. With this variation in mode of operation, it is impossible to impose cookie-cutter regulations without creating fatally adverse consequences for the RLV industry. The only way to ensure a viable and healthy industry, which implies healthy competition, is to devise a regulatory framework, which embraces all concepts. Objective 9 is necessary but must be rewritten in accordance with this ultimate objective.

A.4 Comments on Objective 9 Submitted by Rotary Rocket Company

Rotary Rocket Company believes that Objective 9, as presently worded, would destroy the RLV industry. No private company has the financial resources to conduct the environmental assessments and public hearings required on the several hundred locations that might be preplanned contingency landing/abort sites during a flight test campaign utilizing several ascent profiles. Rotary Rocket Company intends to identify and classify a spectrum of contingency landing sites so that pilots have an instant list of the “best” to the “worst” locations they could reach based on the type of malfunction encountered and the time during the flight it was manifested. These lists will be available to AST prior to the start of the flight test phase so that the government can be assured of the prudent nature of the flight test campaign. Specific pre-approval for each of hundreds of contingency sites that have vanishingly small probabilities of ever being utilized would be absurd.

Information on scheduled launches should be disseminated to any air traffic in the area as part of regular operations for RLVs. In addition, Rotary Rocket Company believes that an abort on ascent to orbit should be considered an emergency. Air traffic control should clear airways as they do when any other aircraft has an emergency and the RLV on its abort flight should be given priority over other air or space traffic.

A.5 Comments on Objective 9 Submitted by Lockheed Martin & concurred by Scitor Corporation

It is impossible to arrange for abort landing sites under the entire flight path of an RLV. In fact, it is also impossible to make a similar arrangement for a commercial airliner. It is impossible because most RLV's must reduce their weight by expending propellant prior to landing (similar to some fighter aircraft.) However, selected abort options can be an important part of an overall safety strategy. We therefore recommend replacing the original Objective 9 with the following:

Objective 9: Pre-planned, Pre-approved Impact Points, Contingency Landing Sites and Contingency Abort Sites

Pre-planned/pre-approved contingency abort landing sites (or impact points for controlled flight into terrain) might be desired to mitigate the hazards associated with some failure modes. The operator's safety plan must establish the failure modes for which an abort is more favorable than continuing the planned mission. If the operator intends to use pre-planned impact sites or abort landing sites they must be large enough to ensure that all RLV landing hazards are contained within the designated site. These sites should avoid air traffic routes or implement mitigating measures to avoid air traffic at the time of reentry.

A.6 Comments on Objective 9 Submitted by ASTI

A major problem exists with use of the term “staging impact points” for RLV boost systems that are fully reusable themselves. Impact implies an uncontrolled arrival.

2.10 Objective 10: Flight Test Demonstration Program

" Inland populations should not be exposed to unreasonable risk of harm from unproven RLV systems. RLV’s that are intended to operate from inland sites involving substantial over-flight of populated areas to achieve their mission, should perform a flight test demonstration program. Test flights can demonstrate that the RLV can perform the critical abort and recovery maneuvers necessary to fly safely over populated areas. Flight test demonstrations would be conducted over unpopulated areas or over areas so sparsely populated that the acceptable risk levels of $E_C < 30\text{x}10^{-6}$ can be achieved assuming a probability of failure = 1 while over the populated area.”

The Working Group agrees that

1. Test flights should indeed be conducted with the greatest of care;
2. Requiring the demonstration of abort and recovery maneuvers in a flight test program, which by definition consume design margin and threaten the vehicle’s integrity, may be inappropriate for many RLV’s. Both abort and recovery maneuvers, however, can be demonstrated in both a flight simulator and Combined System Test (Hardware In The Loop) on the ground;
3. The dichotomy of inland populations versus coastal populations is a false one, and inland populations should not require special treatment in hazard analyses relative to other populations;
4. Requiring the use of a failure probability of 1.0 for hazard analysis calculations is arbitrarily conservative and unwarranted, and would serve to stifle RLV development in the United States.

Attachments to Objective 10 Recommendations

A.1 Comments on Objective 10 Submitted by Kistler Aerospace

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 RLV’s, 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 a test and 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

A.2 Comments on Objective 10 Submitted by Vela Technologies

1) Change “Inland population…” to “The public, in general,…” and change “…operate from inland sites involving…” to “…operate from sites involving…”. There is nothing about inland sites or inland population that warrant addressing them differently from the public at large.
2) Change “…should perform a flight test demonstration program.” To “should perform a flight test demonstration program to the extent necessary to address open issues regarding safety levels (E_c calculations if they are used).
3) Delete reference to E_c calculation using an assumed failure probability of 1. If E_c has any meaning at all, it should be calculated using expected probabilities at all times. The only reason a flight test would be run in the first place would be to reduce uncertainty in the calculated E_c. As the flight test envelope is expanded, appropriate (non-1) probabilities should be used.
4) Using instantaneous impact point (IIP) control as the method of controlling risk requires a continuous assumption of probability of failure as 1. An incremental flight test program (even for aircraft) assumes an increasing demonstration of the flight envelope and does not foster such a draconian assumption throughout the flight test program.
5) A flight test program for the purposes of obtaining licensing is NOT “typically performed in order to learn more about system performance”; but, rather, to demonstrate performance. Assuming “learning about performance” is not the issue, the rationale of probability of failure=1 contained in this objective discussion are unwarranted.

A.3 Comments on Objective 10 Submitted by TGV Rocket

TGV proposes that a P(f) of 0.5 while over population on an initial flight be used, and that each test flight be used to recalculate P(f) on a continuous basis.

A.4 Comments on Objective 10 Submitted by Lockheed Martin

We believe the flight test program should be fashioned to demonstrate operability within the design envelope. The flight test phase should be used to increase confidence in our reliability assessment by demonstrating successful flight. We must fully embrace the E_c process to determine trajectory and other flight parameters. However, an added measure of safety can be imposed by either a) lowering the E_c threshold; or b) using a modified (i.e. more stringent) Pf (probability of failure) based upon similar vehicle historical data. Note that exit criteria should not be a function of payload or the quantity of flight test instrumentation etc. The operator will open the operational envelope by incrementally expanding the independent flight variables and demonstrating successful flight. After the flight test phase is completed, the operator should receive a license to operate the vehicle indefinitely within the established envelope as long as the E_c is below the acceptable threshold. This technique allows the operator to conduct the flight test program from the same location as the operational launch site while protecting the public from undue risk.

We fear the statement ("IIP never over-fly a populated area") is too restrictive if not impossible. Recommend utilizing the Ec technique above since it will compensate for IIP dwell time. It should be noted that the IIP of all ELV's circumvents the globe. Hence, they also operate over large landmasses during launch. This situation is mitigated by the reduction in dwell time when the IIP is at long range. The E_c techniques currently in use automatically compensate for this fact.

When comparing flight test data with analytically predicted data, we should, If possible, specify the acceptable threshold to be considered "a good comparison between analytical and flight test data" (e.g. two sigma, three sigma etc.)

Upper stages that do not significantly impact public safety should not be included in the list of monitored parameters during flight test.

We recommend using E_c to provide a tangible measure of risk. This technique can be used to protect all population centers despite their location around the globe. However, the requirement to calculate $E_c < 30$ E-06 using probability of failure = 1 is excessively restrictive and warrants careful consideration and discussion. Industry is incentivised to design, build and operate an RLV to a much higher reliability standard when compared to an ELV. We suggest the use of a more reasonable Pf value. One approach would be the use of Pf based upon historical data from other vehicles with similar configuration and heritage. For example, one might determine Pf based upon all previous vehicles with liquid first stages using similar technology. In any event, it is most important that industry and government agree upon the metric at the beginning of the program.

Review of previous history suggests that an all liquid stage with engine out capability will be highly reliable:

After 144 flights of 5 different designs, no American liquid fueled stage with engine out capability has been lost to a propulsion failure. A review of recent first flight failures found the following causes:

- Bad aero data base - Pegasus XL, Delta III
- Subsystems qualified wrong environment - LLV
- Lack of appropriate software verification - Ariane V

Appropriate first flight certification plan will prevent these failures.

A.5 Comments on Objective 10 Submitted by Kelly Space & Technology, Inc. (KST)

1.0 KST concurs with the comments submitted by Kistler Aerospace.

2.0 KST concurs with the comments submitted by Vela Technology.

3.0 KST concurs with the comments submitted by TGV Rockets that using an initial P_f less than 1 and recalculating for subsequent flights is a much more reasonable approach.

4.0 Flight tests are of paramount importance in the development of a RLV system. Unfortunately, as has been pointed out by several developers, the cost of each flight test for a RLV compared to that for an aircraft is so much greater and the production volume for a RLV compared to an aircraft so small that the cost of numerous flight tests for a RLV system would make RLV programs not viable.

Although a limited number of flight tests are essential to demonstrate operability, the number required can be reduced significantly by rigorous ground tests. The FAA should consider a developer's proposal to conduct rigorous ground tests as an alternate to an exhaustive series of flight tests. Any test program, either ground or flight, enables the developer to learn more about the system's performance, however this is not the primary objective of a flight test demonstration program. The emphasis of the RLV flight test program should be demonstration of performance, not enhancement.

Some RLV developers propose to use as much off-the-shelf (OTS) equipment as possible. This equipment has a demonstrated history of performance and reliability. Extensive ground testing will be performed to evaluate new interfaces and interactions between other subsystems and components while gaining additional history regarding performance of the OTS equipment in the RLV application. The developer should be allowed to use these demonstrated reliabilities not only in E_c or other calculations, but also to provide the FAA with increased confidence that the RLV system will function as predicted in the flight environment.

Demonstration of abort procedures in a flight test would indeed compromise system integrity. Many developers have pointed out, on numerous occasions, that the use of minimum, but adequate, design margins is essential to a cost-effective approach to both placing a payload in orbit and delivering a sub-orbital payload. This fact needs to be re-emphasized. The FAA should allow the developer to develop and test abort maneuvers and procedures in a simulated environment to the maximum extent possible.

It is clear that the use of a P_f of 1 for all flight tests is unacceptable. Therefore, it is essential that the FAA and each developer devise an approach to determining a reasonable P_f for flight testing the developer’s RLV. This approach should be reflected in the regulatory framework established between the FAA and the developer for that RLV.

A.6 Comments on Objective 10 Submitted by Rotary Rocket Company

Rotary Rocket Company believes that it is not appropriate to use a probability of failure of 1 for a vehicle that has undergone a component-testing program. The probability that should be used should be dependent on the details of the component testing program and the characteristics of each company's development program. Rotary Rocket Company would also like to recommend that with each successive flight demonstration, the probability of failure be decreased by some exponential factor or by some form of other statistical method that is recognized as an industry standard.

A.7 Comments on Objective 10 Submitted by ASTI

ASTI concurs with the WG that an assumed probability of failure (P_f) of 1 for flight test demonstrators is completely unrealistic. If there were a system that was almost ready for flight test with a P_f of 1, the test vehicle should be mounted on a pedestal instead of used for flight test.

2.11 Objective 11: Preflight Inspection and Checkout

"Prior to each flight, RLVs should undergo system monitoring, inspection and checkout to ensure that all critical systems are functioning within intended parameters and are not otherwise impaired or degraded."

The Working Group agrees that

1) Prior to each flight, RLVs should undergo any required refurbishment, system monitoring, inspection and checkout to ensure that all critical systems are functioning within intended parameters and are not otherwise impaired or degraded;

2) In the process of ensuring vehicle return, each developer will determine the maintenance program most appropriate for his system;

3) The FAA should be attentive to each developer's rationale when assessing monitoring, inspection, and checkout programs rather than anticipating that a single assessment standard will serve all developers.

Attachments to Objective 11 Recommendations

A.1 Comments on Objective 11 Submitted by Vela Technologies

In the first sentence of the discussion, replace “RLV’s” with “anything”: rationale-there is nothing more or less inherently risky in RLV’s.

A.2 Comments on Objective 11 submitted by Kelly Space & Technology, Inc. (KST)

1.0 Objective 11 should be revised to read: "….should undergo the required refurbishment, system monitoring…"

2.0 KST recommends replacing "RLV's" with "launch vehicles" rather than "anything" as recommended by Vela Technologies.

3.0 Pre-flight inspection and checkout is an accepted practice for all aircraft as well as launch vehicles. RLV's, regardless of concept, have the additional requirement of pre-flight refurbishment which will be unique for each concept. This requirement should be defined in the Licensing Plan established between the FAA and the developer for the developer's system.

A.3 Comments on Objective 11 Submitted by Rotary Rocket Company

Rotary Rocket Company believes that preflight inspection, maintenance and checkout should be conducted for components to the same level of detail that they have been designed for. When use of a currently available system is subjected to significantly different conditions that what was intended, modifications to the IMC program should be made to account for these differences. The necessary modifications to these programs should be determined jointly by the manufacturer and the RLV developer. If a system has been uniquely designed and manufactured by the RLV developer, it should determine the level of IMC that is necessary and appropriate. Systems or components with similar designs and operating conditions should be used as a guideline for defining the IMC program. Operational data gathered through the operational use of a new system should be used along with external contractors to aid in arguing acceptance for the developer proposed IMC program.

A.4 Comments on Objective 11 Submitted by ASTI

There is a direct correlation between an aircraft’s preflight checklist, and that of an RLV. That’s what both the RLV industry and the FAA should be striving towards.

PART 3

<u>Regulatory Framework for RLV’s, RLV Working Group Recommendations</u>

PROPOSED REGULATORY FRAMEWORK
FOR THE
LICENSING OF REUSABLE LAUNCH VEHICLES

3.1 INTRODUCTION AND APPROACH

3.1.1 Justification for a New Regulatory Framework for Reusable Launch Vehicles Allowing Individualized Approaches to RLV Licensing

3.1.1.1 The Commercial Space Transportation Advisory Committee (COMSTAC) Reusable Launch Vehicle (RLV) Working Group has been attempting to define a regulatory regime for RLVs. This effort is made challenging by the diversity of vehicle configurations, flight scenarios, and capabilities. The Working Group believes that this diversity reflects a healthy, creative industry and should not be discouraged.

3.1.1.2 In attempting to develop a licensing regime to recommend to the FAA, the members of the RLV Working Group recognized that each proposed approach assumed, either implicitly or explicitly, a system concept, or at best a small range of concepts. In attempting to combine these various approaches, the Working Group realized it would be difficult for a single licensing regime to fairly address all of the concepts under development for the following reasons:

a. Firstly, the Working Group realized that imposing a single licensing regime upon all RLV systems could inhibit innovation, technical advancement and competition in the emerging RLV industry.

b. Secondly, the Working Group concluded that a single licensing regime might not be required to assure public safety. Indeed, a single regulatory regime could dispose prematurely of innovative approaches to safety and risk mitigation that might advance public safety and ultimately benefit the entire industry.

3.1.1.3 *The RLV Working Group concluded, therefore, that a single licensing regime to serve all concepts is not only improbable, but also undesirable. Rather, RLV regulations should provide a legal framework within which a clear path to licensing can be determined for each system configuration.*

3.2 DESCRIPTION OF REGULATORY FRAMEWORK

3.2.1 Summary

Under the proposed Regulatory Framework, each developer will submit a Licensing Plan for negotiation and agreement with FAA/AST (AST). Once agreed, the Licensing Plan will be binding upon both the applicant and the AST. Any changes or waiver requests to an applicant's Licensing Plan will be submitted to AST with detailed rationale/documentation and approved by AST as an amendment to the applicant's Licensing Plan. Satisfactory completion of the tasks agreed to in the Licensing Plan would be sufficient for the FAA to issue a Launch License.

In recognition of the FAA's primary mission in regard to the safety of the public, this Licensing Plan will identify, in advance, the threshold(s) against which an applicant's safety assessment will be measured. It will explain the chosen methodology, and present the tools to be used in the analysis. This methodology may be a maximum expected casualty (E_c) calculation, or some other methodology proposed by the developer and agreed to by the FAA.

If the applicant proposes to conduct an E_c computation, the Licensing Plan will detail the method in which it is to be calculated and the analyses, tests and other documents that must be performed to substantiate the numbers used in the calculation. If some other methodology is used, the analyses, tests and documentation that must be performed to show an acceptable level of safety will be specified. In either case, the completion of credible analysis resulting in attainment of the agreed upon assessment criteria shall be grounds for licensing.

3.2.2 Licensing Guidelines for RLV Applicants

To aid applicants, the AST will develop and issue Licensing Guidelines for RLV Applicants. The Guidelines will set forth the submissions, methodologies and criteria that, when followed by the applicant, will lead to the issuance of a license. The RLV Working Group expects that the FAA initially will draw from licensing criteria used in licensing Expendable Launch Vehicles (ELVs), until it develops independent experience in licensing RLVs.

These Guidelines would be instructive, but not mandatory, to encourage innovation and to avoid rigid regulatory requirements. The Guidelines would evolve over time as the industry matures and the FAA gains experience in licensing various RLV systems. The topics addressed by the FAA Safety Guidance for RLVs (issued January 1999) might be incorporated in these Guidelines. (The RLV Working Group's comments on the FAA Safety Guidance are set forth in Part 1.)

If the applicant believes that the applicant's system configuration, operations, or vehicle design warrants a variation from these guidelines, the applicant will explain and justify the variation in the negotiation of the Licensing Plan. In assessing variations, the FAA will take into consideration the vehicle configuration, whether the vehicle is manned or unmanned, the proposed site of operations, and other factors related to public safety.

3.2.3 Licensing Plan

(a) Procedures for Negotiation of Licensing Plan; Legal Effect

Early in the licensing process, an applicant would propose to the AST a Licensing Plan defining licensing requirements for the applicant's proposed launch operations. The Licensing Plan would define required documentation, analyses, methodologies and tests, and a schedule for these submissions. The proposed plan would clearly identify any variations from the AST Guidelines.

Upon formal submission of a complete Licensing Plan, the AST will have 90 days in which to respond formally. It is anticipated that the applicant would consult with the AST on the Licensing Plan both before formal submission and during the 90-day review period.

The AST may accept or reject the Licensing Plan. The AST will state the reasons for rejection of the proposed Licensing Plan. Once agreed, however, the licensing plan will be binding upon both the applicant and the AST.

The Licensing Plan, at all times, is the possession of the developer. It is the developer's prerogative to formally submit it at any time to the AST for acceptance or rejection.

(b) General Content of Licensing Plan

The Licensing Plan does not comprise the documents, analyses, and test reports themselves. Rather, the Licensing Plan is an outline in which the developer is proposing a set of documents, tests, and analyses, and a description of their contents adequate to enable the FAA/AST to reach a determination on the sufficiency of information that subsequently *will* be presented in the licensing process.

The Licensing Plan proposal accordingly will include a reasonable description of the documents and their contents. It is the responsibility of each developer to present clear descriptions of his proposed submittals to AST for discussion along with justification for any variation from the Guidelines. AST will strive to identify acceptable methodologies and techniques for producing the required documentation.

Documents to be submitted by the developer may include:

- Substantive System Definition
- System engineering and integration plans
- Verification and validation plans and results
- FMECA and critical components list
- System safety and health plans
- Contingency and emergency management
- Maintenance and refurbishment plans
- Flight test program
- Probabilistic risk assessment

Each developer is responsible for proposing an assessment methodology and criterion (a). Examples of assessments requiring specific methodologies include casualty expectation analysis and FAR compliance, or any other methodology and criteria proposed by the applicant. The methodology and criteria may be qualitative or quantitative as the developer sees most appropriate for his system.

(c) Schedule of Submissions

Each proposed Licensing Plan will include a schedule culminating in a date for issuing the license. The schedule should include submittal dates, AST response dates, meeting dates to resolve disagreements, and, finally, a license issuance date.

APPENDIX A

Licensing versus certification

(This appendix, addressing the advantages and disadvantages of RLV Licensing and Certification, was copied verbatim from the Interim Report dated 4 February 1999)

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[3] 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

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

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 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[4] 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

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[4] 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.

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 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[5] (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[6]. 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 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.

<u>Recommended Approach to Licensing</u>

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[7] to design their vehicles, FMECA, PRA, ORM.

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[5] Refer to Appendix A for details, referenced from [3] and [4].

[6] Refer to the discussion on the Roton Maintenance Program in Section 9.

[7] 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.

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 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."[8]

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.

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[8] 49 U.S.C. 70101(b)(1) & (2).

2.2a. Arguments in favor of “licensing”

In the view of certain participants of the RLV Working Group,[9] 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 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.

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

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.

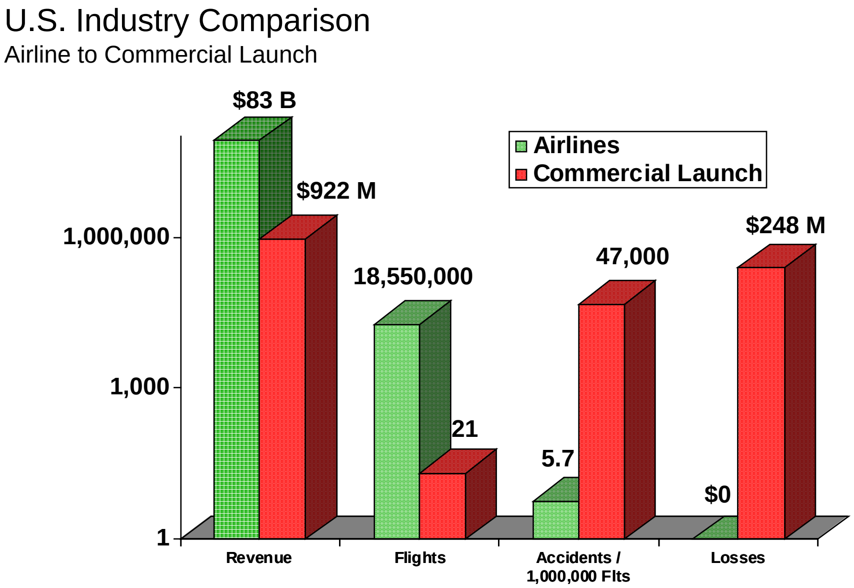

Figure 1

SA002143-AJ-01-RR-E

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 $P_{pf} = 1.08 \times 10^{-7}$ / Flt Hr
  - 92 Crew/Passenger Fatalities $P_{c/pf} = 5.07 \times 10^{-6}$ / Flt Hr
  - 65 Accidents / 11,455,000 flights $P_a = 5.7 \times 10^{-6}$ / Flight
  - Passenger Casualties $P_c = 3.68 \times 10^{-8}$ / Flight*
    - Passenger Serious Injuries / Enplanements
      - Reference NTSB Table 3
  - Public Expected Casualties $E_c = 1.75 \times 10^{-7}$ / 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**

SA002144-AJ-01-RR-E

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 $P_a = 4.7 \times 10^{-2}$ / Flight*
  - New Vehicle Failures $P_f = 4.0 \times 10^{-1}$ / Flight

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

SA002145-AJ-01-RR-E

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

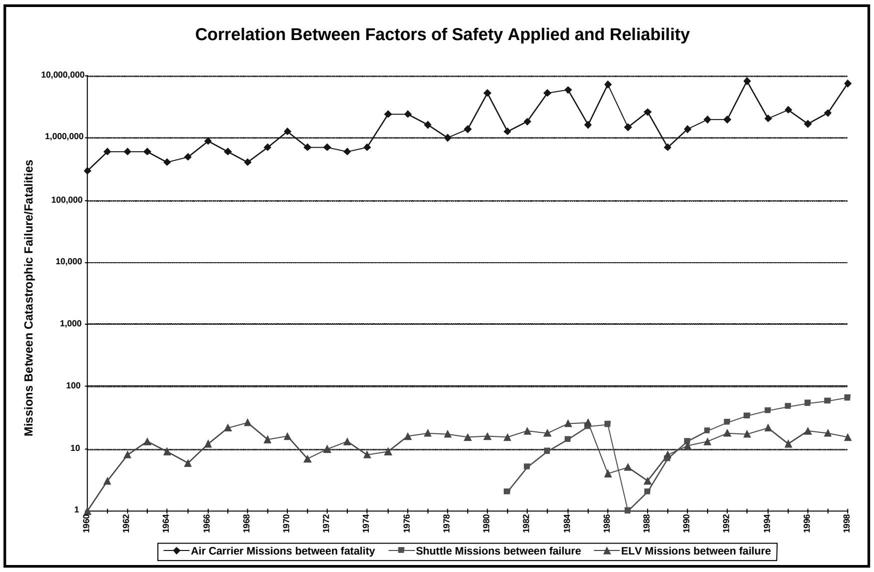

Figure 4

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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.

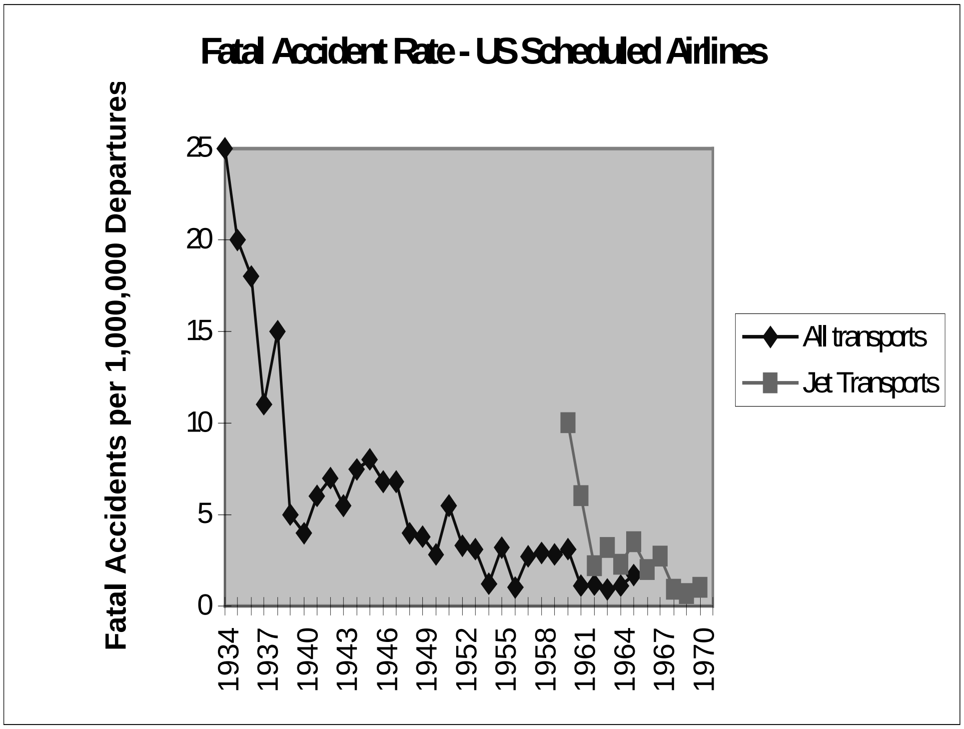
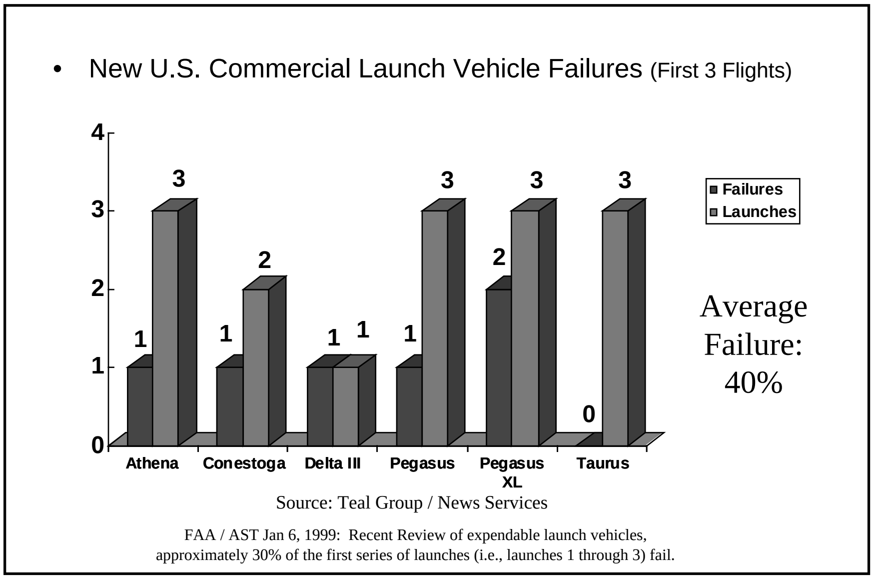


Figure 5

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.



- New U.S. Commercial Launch Vehicle Failures (First 3 Flights)

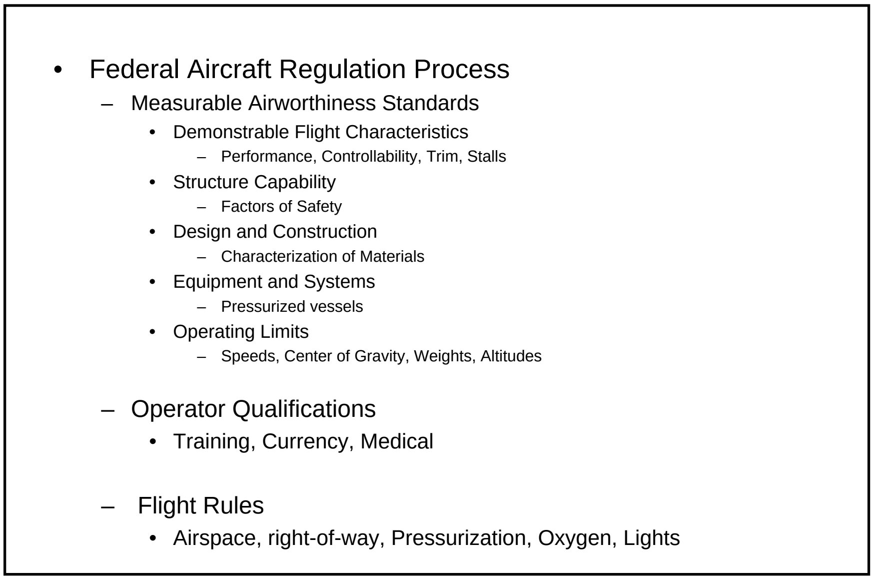
Average Failure: 40%

Source: Teal Group / News Services

FAA / AST Jan 6, 1999: Recent Review of expendable launch vehicles, approximately 30% of the first series of launches (i.e., launches 1 through 3) fail.

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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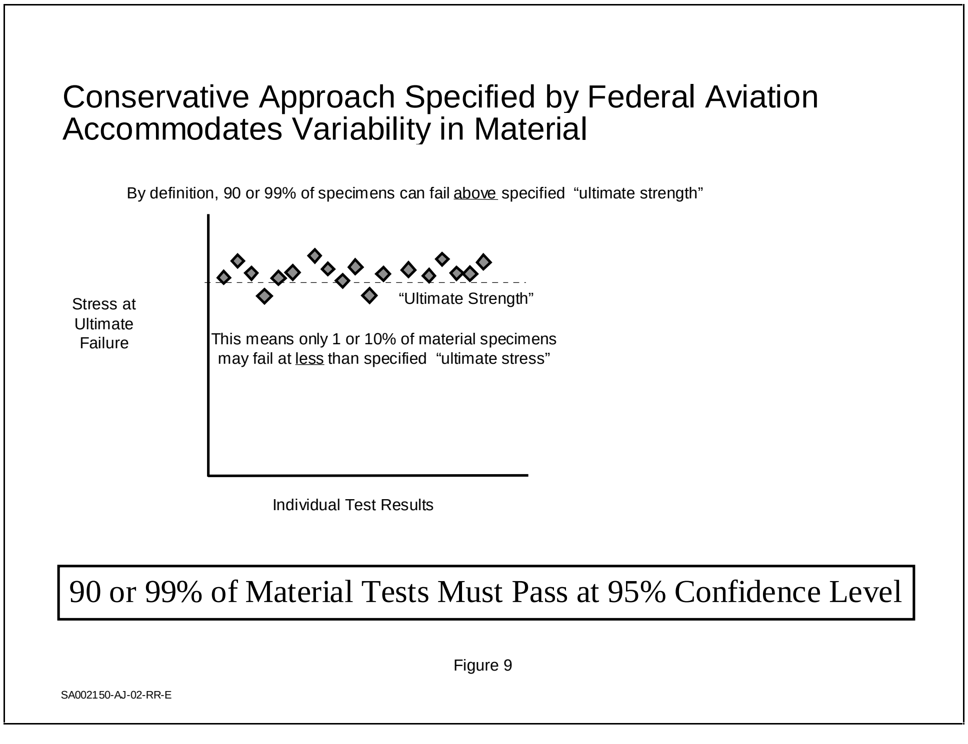
Figure 8



Conservative Approach Specified by Federal Aviation Accommodates Variability in Material

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

This means only 1 or 10% of material specimens may fail at less than specified "ultimate stress"

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.

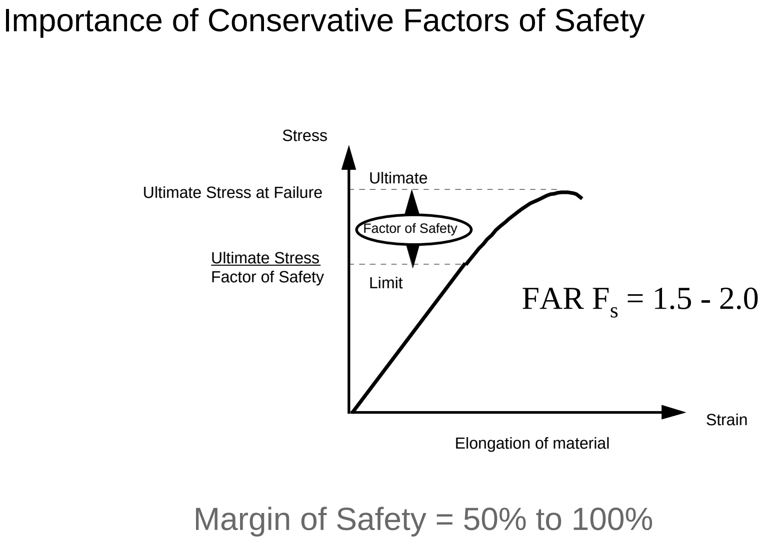

Figure 10

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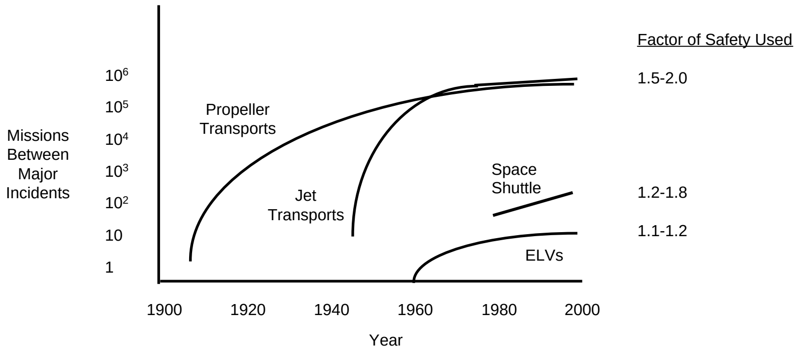
The FAR process uses historical information to account for past failures and provide redundant equipment and systems. Well-characterized materials take into account the variability of material properties by doing extensive coupon testing required of the certification process. It requires quality and 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.

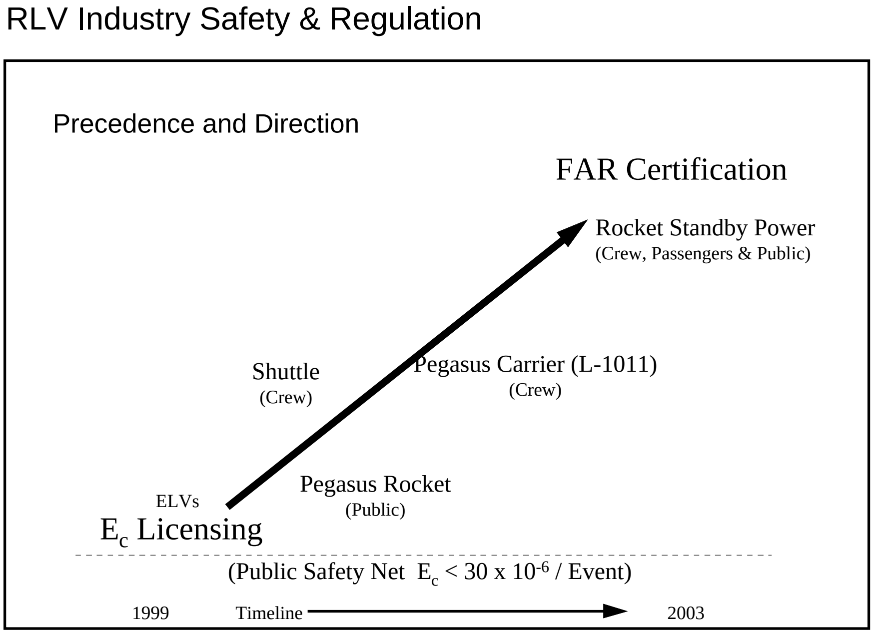

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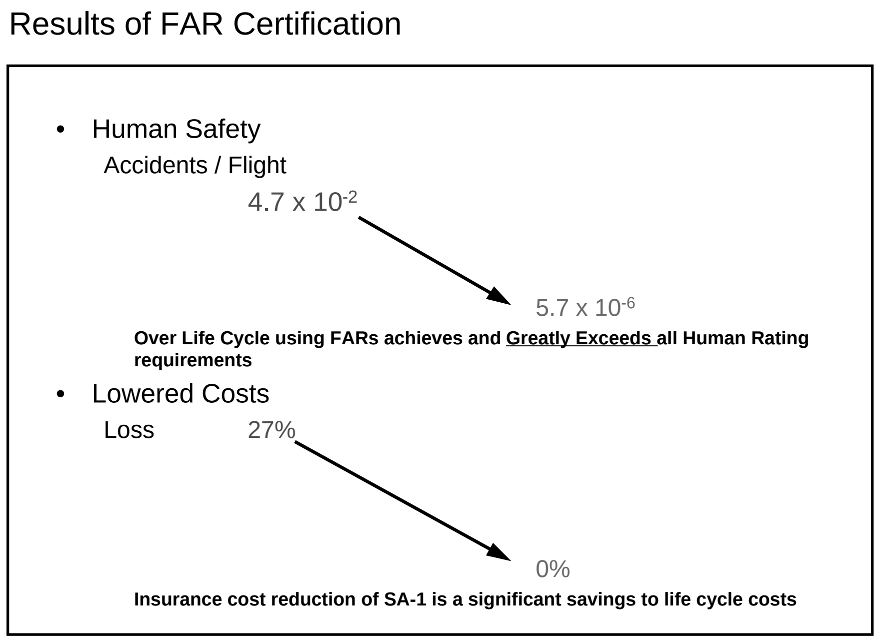
Figure 12

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.



Results of FAR Certification

- Human Safety

  Accidents / Flight

  4.7×10^{-2} → 5.7×10^{-6}

  Over Life Cycle using FARs achieves and __Greatly Exceeds__ all Human Rating requirements

- Lowered Costs

  Loss 27% → 0%

  Insurance cost reduction of SA-1 is a significant savings to life cycle costs

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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.

APPENDIX B

Interim Safety Guidance for Reusable Launch Vehicles, Draft

DRAFT
Interim Safety Guidance
for
Reusable Launch Vehicles

Table of Contents

PREFACE

The Associate Administrator for Commercial Space Transportation (AST) has developed draft interim safety guidance for use by an applicant for a license to operate a reusable launch vehicle (RLV). This guidance is intended to assist an applicant in responding to public safety concerns of the agency associated with an application to conduct RLV operations.

The safety objectives presented in this interim safety guidance are not regulations. The guidance reflects the agency's general policy of ensuring public safety is not jeopardized as a result of new launch vehicle technology. Until the FAA issues regulations that address the unique safety aspects associated with reentry of reentry vehicles and Reusable Launch Vehicle (RLV) operations, the FAA will consider license applications for RLV launch and reentry on a case-by-case basis, taking into account the operational capability of a proposed vehicle. Development of a license application by an RLV operator is facilitated through early and frequent consultation between the applicant and the agency to assure public safety issues are identified and adequately addressed by the applicant. To the extent appropriate, existing licensing regulations will apply to applications to launch or reenter an RLV. However, for those unique safety aspects associated with RLV or reentry operations, the FAA is providing this interim safety guidance that reflects public safety concerns of the FAA in evaluating a license applicant's ability to conduct safe launch and reentry operations.

Objective 1: Public Expected Casualty

The public should not be exposed to an unreasonable risk of harm as a result of RLV operations. Risks to public safety will be measured in terms of collective risk, similar to launches from Federal ranges. The risk to the public for Reusable Launch Vehicle (RLV) operations shall not produce a total public casualty expectancy (E_C) greater than that allowed by Federal ranges, that is 30×10^{-6} during the launch and reentry phase of a mission. This per mission E_C includes both launch and reentry risks as parts of a single mission.

(The launch and reentry phases of an operation together are regarded as one mission that must satisfy this E_C criterion.)

Discussion:

This objective of limiting expected casualty[10] to 30×10^{-6} for RLV operations is consistent with current guidelines and standards for public risk for launch activities of expendable

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[10] Expected Casualty (E_C) is used as a measure of public safety and is typically one of the measures used to determine whether a launch should not proceed because of public safety concerns. The measure represents the collective risk measured as expected "average number of casualties" for the specific mission. A tutorial on Expected Casualty can be found in Attachment 2.

launch vehicles (ELVs) at Federal (DOD) ranges.[11] It is anticipated that there may be situations where separate launch and reentry operators may be seeking licenses for operations that result from the same mission event. This objective considers that ascent and reentry are effectively one mission with risk allocated in whatever matter desired as long as the total mission exposure does not exceed the E_C threshold of 30 x 10^{-6}.

Most ELV operations are launched out over the ocean where the population density is extremely low. ELV safety systems (destructive flight termination systems) are designed to prevent the possibility of the vehicle flying over populated areas for extended periods early in the flight and it is these safety systems that get the most safety scrutiny. In the case of ELVs, other vehicle systems that affect the reliability of the vehicle are less important to safety because a launch vehicle failure over the ocean presents minimal public exposure to risk. Even a relatively high probability of a catastrophic vehicle system failure presents very little safety concern because of the extremely low population densities in the ocean. On the other hand, vehicles that are to be operated over land may expose the public during flight and such measures as performance and reliability of the vehicle and its safety systems all materially affect public safety. This may mean that the level of effort to provide a high level of confidence of system performance and reliability will entail the need for more rigorous analysis and testing. In addition, restrictions, including flight testing over unpopulated or sparsely populated areas, may be needed. The nature of RLVs entail design and performance characteristics that differ from ELVs, such as the reusability factor – flying the same vehicle over and over again, or the concept of new flight safety systems – permitting a vehicle to safely abort its mission during flight under certain circumstances without necessarily requiring its destruction.

Risk Statistics

An E_C risk threshold reflects acceptable collective risk, as opposed to individual annual risk, which describes the probability of serious injury or death to a single person, and is perhaps, the more common measure of risk used in other industries. The launch industry's common measure of risk is collective risk, which may then be measured as individual risk in light of the factors associated with any given launch. Individual risk may be correspondingly less than collective risk, depending on the size of the population exposed. This means that a collective risk of E_C of 30 x 10^{-6} may be more strict than an individual risk of 1 x 10^{-6} (1 per million). For example, with a collective risk of 30 x 10^{-6}, and a population of one hundred thousand exposed to a particular launch, the risk to any one individual is 0.3 x 10^{-9} (three tenths per billion). For purposes of comparison, the FAA notes that the Air Force describes this collective risk level as no greater than that voluntarily accepted in normal daily activity (Eastern and Western Range 127-1 Range Safety Requirements, Sec. 1.4, 1-12 (Mar. 31, 1995)).

Attachment 2 of this document provides a general description, with simplified examples, of the application of expected casualty to space transportation.

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[11] The Air Force Range Safety Requirements (EWR 127-1) establishes this risk threshold as a level that if exceeded, higher approval authority is required. To AST's knowledge, no licensed commercial launch has been allowed to proceed which would exceed this threshold for a mission.

Objective 2: Safety Process Methodology

In addition to the expected casualty objective, an applicant should apply a disciplined, systematic, and logical safety process methodology for the identification and control of hazards associated with its launch and/or reentry systems.

Explanation of Methodology of General System Safety Process:

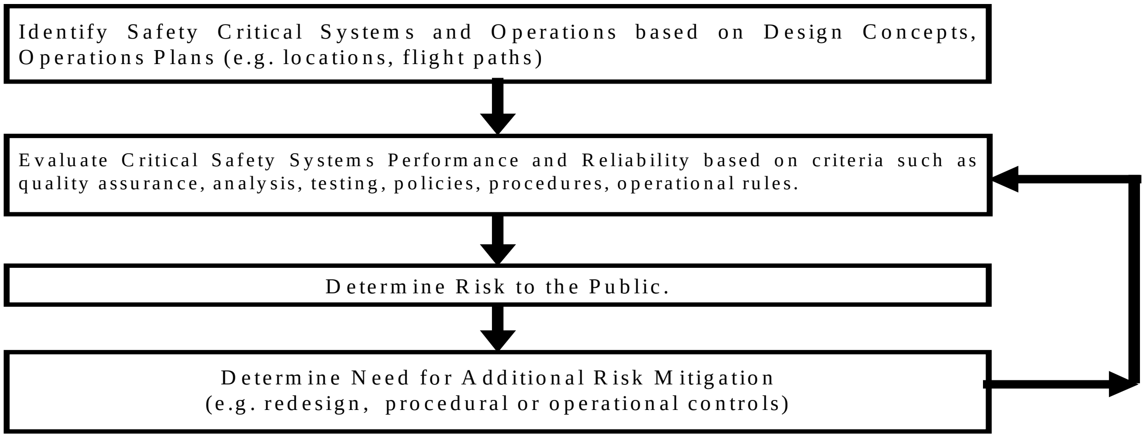

FIGURE 1: SAFETY PROCESS FLOW

The Applicant should use a System Safety Engineering Process or its equivalent, which includes a Risk Analysis, to show that it meets the safety process methodology criteria identified above. The process flow depicted in Figure 1 represents a top level outline of the traditional systems safety engineering process successfully used by DOD and NASA for decades, modified to focus only on risks to public safety. The process depicted is ongoing until all potential risks have been mitigated to an acceptable level. The System Safety Engineering Process used may be similar to that reflected in Military Standard 882C, or the System Safety Analysis Handbook (a System Safety Society Standard), or FAA Advisory Circular “AC No: 25.1309” titled “System Design and Analysis”.

The use of a systematic process for the identification and control of safety critical systems and operations also provides the foundation supporting the Expected Casualty analysis. Without a process that helps assure a disciplined approach to the design, manufacture, integration, test, and operation of a system, it will be very difficult to establish any confidence in the probabilities of success and failure provided for the Expected Causality analysis. It is also noted that although the application of a system safety process is extremely important in creating a strong foundation for assuring the safety of a system, it does not in and of itself assure public safety. The combination of the system safety engineering approach with the expected causality analysis and the other applicable objectives in this guidance document is intended to help ensure an adequate level of public safety. See Figure 1B.

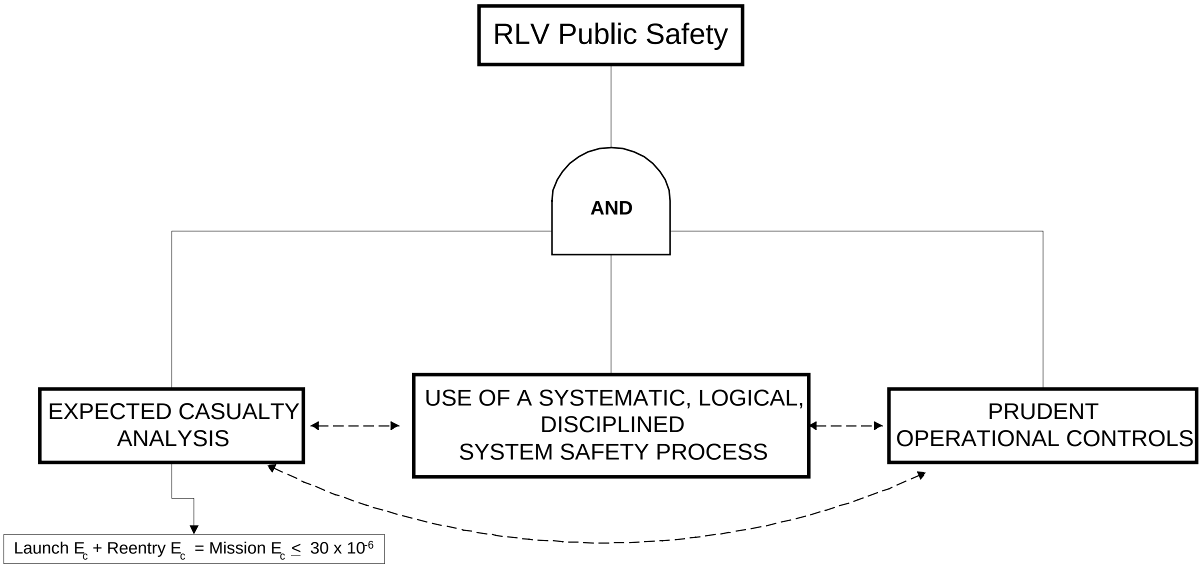

Figure 1B: RLV Public Safety

A more detailed description of the System Safety Engineering Process and a Flow Chart showing the relationship of the process to the system development are included in the attached instructional tutorial (Attachment 1). While Risk Analysis is mentioned in the same attachment, a top-level description with simplified examples of the analysis and measurement of risk (via expected casualty) can be found in Attachment 2. The following is a brief description intended to provide examples of the system safety process and analysis techniques, examples of safety critical systems, and typical analytical and test procedures used to verify safety critical systems and potential operational controls/constraints.

System Safety Engineering Process

The System Safety Engineering Process is the structured application of system safety engineering and management principles, criteria, and techniques to address safety within the constraints of operational effectiveness, time, and cost throughout all phases of the system's life cycle. The intent of the System Safety Engineering Process is to identify, eliminate, or control hazards to acceptable levels of risk throughout a system's life cycle.

This process is performed by the vehicle developer/operator. Because of the complexity and variety of vehicle concepts and operations, only such a process can ensure that all elements affecting public safety are considered and addressed. Without such a process, very detailed requirements would have to be imposed on all systems and operations, to ensure that all potential hazards have been addressed which could have the undesired effect of restricting design alternatives and innovation or could effectively dictate design and operations concepts.

The process (as described in Mil Std 882C, etc.) includes the requirement for a System Safety Program Plan (SSPP). The SSPP (or its equivalent) provides a description of the strategy by which recognized and accepted safety standards and requirements, including organizational responsibilities, resources, methods of accomplishment, milestones, and levels of effort, are to be tailored and integrated with other system engineering functions. The SSPP lays out a disciplined, systematic methodology that ensures all hazards – all events and system failures (probability and consequence) that contribute to expected casualty – are identified and eliminated, or that their probability of occurrence is reduced to acceptable levels of risk (per objective 1,6,8, and 10).

The SSPP should indicate the methods employed for identifying hazards such as Preliminary Hazards Analysis (PHA), Subsystem Hazard Analysis (SSHA), Failure Mode and Effects Analysis (FMEA), Fault Tree Analysis, etc. Risk Mitigation Measures are likewise identified in the plan. These include avoidance, design/redesign, process/procedures and operational rules and constraints.

Identification of Safety Critical Systems

For the purposes of a System Safety Engineering Process safety critical systems are defined as any system or subsystem whose performance or reliability can affect public health, safety and safety of property. Such systems, whether they directly or indirectly affect the flight of the vehicle, may or may not be critical depending on other factors such as flight path and vehicle ability to reach populated areas. For this reason it is important to analyze each system for each phase of the vehicle mission from ground operations and launch through reentry and landing operations. Examples of potentially safety critical systems that may be identified through the system safety analysis process using PHA or other hazard analysis techniques may include, but are not limited to:

- Structure/integrity of main structure
- Thermal Protection System (e.g., ablative coating)
- Temperature Control System (if needed to control environment for other critical systems)
- Main Propulsion System
- Propellant Tanks
- Power Systems
- Propellant Dumping System
- Landing Systems
- Reentry Propulsion System
- Guidance, Navigation and Control System(s), Critical Avionics (Hardware and Software) - This includes Attitude, Thrust and Aerodynamic Control Systems
- Health Monitoring System (hardware and software)
- Flight Safety System (FSS)
- Flight Dynamics (ascent and reentry) for stability (including separation dynamics) and maneuverability
- Ground Based Flight Safety Systems (if any) including telemetry, tracking and command and control systems
- Depending on the concept, additional “systems” might include pilot and life support systems and landing systems if they materially affect public health and safety
- Others identified through hazard analysis

Validation of Safety Critical Systems

An Applicant should be able to demonstrate that the proposed vehicle design and operations will satisfy the safety objectives of this guidance material and that the system will survive and perform safely in all operating environments including launch, orbit, reentry and recovery. Documentation should show adequate design, proper assembly, and vehicle control during all flight phases. Documentation is expected to consist of design information and drawings, analyses, test reports, previous program experience, and quality assurance plans and records.

The FAA uses a pre-application consultation process to help a potential applicant to understand what must be documented and to help identify potential issues with an applicant's proposed activities that could preclude its obtaining a license. This process is especially important for RLV systems because most are using unique technology and operating concepts. The pre-application process should be initiated by the applicant early in their system development (if possible during the operations concept definition phase) and maintained until their formal license application is completed. This pre-application process should be used to provide the FAA with an understanding of the safety processes to be used, the safety critical systems identified, analysis and test plan development, analysis and test results, operations planning, flight rules development, etc. As a function of the pre-application process the FAA may attend design reviews and system tests, in order to ensure that development, testing and test results are consistent with the analyses, and other demonstrations made to the FAA. See Attachment 1 for additional information.

Analyses may be acceptable as the primary validation methodology in those instances where the flight regime cannot be simulated by tests, provided there is appropriate technical rationale and justification.

Qualification tests, as referenced in the Safety Demonstration Process and the System Safety Program Plan, are normally conducted to environments higher than expected. For example, ELVs' Flight Safety Systems (FSS) are qualified to environments a factor of two or higher than expected. (See Figure 2)

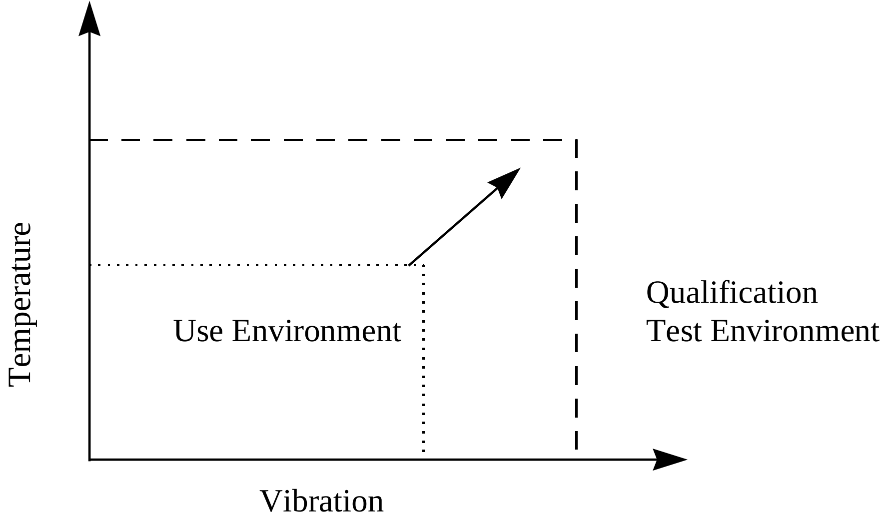

Figure 2. Relationship of Use Environment to Qualification Test Environment

These tests are conducted to demonstrate performance and adequate design margins and may be in the form of multi-environmental ground tests, tests to failure, and special flight tests. Such tests are normally preceded with detailed test plans and followed by test reports.[12] In addition, Quality assurance (QA) records help establish verification of both design adequacy and vehicle assembly and checkout (workmanship).

The following matrix identifies examples of approaches that may be employed to validate acceptance for critical systems. Examples of types of analyses, ground tests, and flight tests are provided following this matrix. (Note: Quality Assurance programs and associated records would be essential where analysis or testing, covering all critical systems, are involved.)

Candidate Critical Systems	Analyses	Ground Test	Flight Test
Structure/Integrity of Main Structure	X	X	P
Thermal Protection	X	P	P
Environmental Control (temp, humidity)	X	X	X
Propulsion: Main, Auxiliary and Reentry (de-orbit)	X	P	P
Propellant Tank Pressurization	X	X	P
GN&C, Critical Avionics *; includes de-orbit targeting (e.g., star-tracker, GPS)	X	X	X
Health Monitoring *	X	X	X
Flight Safety System (FSS)*	X	X	X
Recovery and Landing	X	P	P
Ordnance (other than Safety)	X	X	X
Electrical and Power	X	X	X
Telemetry and Tracking and Command*	X	X	X
Flight Control (ascent, separation, reentry) *	X	X	X
FSS Ground Support Equipment (if any) *	X	X	N/A

P - partial; cannot satisfy all aspects
X - if in sufficient detail when combined with test results or selected analyses

- - includes both hardware and software

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[12] Test plans are important elements of the ground and flight test programs. Such plans define, in advance, the nature of the test (what is being tested and what the test is intended to demonstrate with respect to system functioning, system performance and system reliability). The test plan should be consistent with the claims and purpose of the test and wherever appropriate, depending on the purpose of the test, clearly defined criteria for pass and fail should be identified. A well defined test plan and accompanying test report may replace observation by the FAA.

Analyses

There are various types of analyses that may be appropriate to help validate the viability of a critical system or component. The following provides examples of some types of critical systems analysis methodologies and tools. Again these are *only examples* and should not be construed as the only analyses or software tools which may be necessary to validate a specific system for a specific operational environment, nor should it be interpreted that all of these example analysis and software tools will be necessary to validate a specific system.

Mechanical Structures and Components (Vehicle Structure, Pressurization, Propulsion System including engine frame thrust points, Ground Support Equipment)

- Types of Analyses: Structural Loads, Thermal, Fracture Mechanics, Fatigue, Form Fit & Function
- Software Tools for Analyses: Nastran, Algor, Computational Fluid Dynamics codes, CAD/CAM

Thermal Protection System

- Types of Analyses for TPS and Bonding Material: Transient and Steady State Temperature Analyses, Heat Load, and Heating and Ablative Analyses.
- Software Tools for Analyses: SINDA by Network Analysis Inc.

Electrical/Electronic Systems & Components (Electrical, Guidance, Tracking, Telemetry, Navigation, Communication, FSS, Ordnance, Flight Control and Recovery)

- Types of Analyses: Reliability, FMEA, Single Failure Point, Sneak Circuit, Fault Tree, Functional Analysis, Plume effects
- Software Tools for Analyses: MathCad, Relex, FaultrEase

Propulsion Systems (Propulsion, FSS, Ordnance, Flight Control)

- Types of Analyses: Analytical Simulation of nominal launch and abort sequences for Main Engines, Orbital Maneuvering System (including restart for reentry-burn) and Attitude Control System; capacity analysis for consumables; Plume Flow Field Modeling
- Software Tools for Analyses: Nastran, Algor, SPF-III, SINDA

Aerodynamics (Structure, Thermal, Recovery)

- Types of Analyses: Lift, Drag, Stability, Heating, Performance, Dispersion, Plume effects
- Software Tools for Analyses: Post 3/6 DOF, Computational Fluid Dynamics Codes, Monte Carlo Simulation Codes

Software (Guidance, Tracking & Telemetry & Command, FSS, Flight Control and Recovery)

- Types of Analyses: Fault Tree, Fault Tolerance, Software Safety (including abort logic), Voting Protocol Dead Code, Loops, and Unnecessary Code
- Validation Methodologies, such as ISO 9000-3 [13]

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[13] ISO 9000-3 is used in the design, development, and maintenance of software. Its purpose is to help produce software products that meet the customers' needs and expectations. It does so by explaining how to

Ground Tests

Ground tests include all testing and inspections performed prior to flight, including qualification, acceptance and system testing. It is anticipated that an applicant will perform various types of ground tests to validate the capability of critical systems and components. The following provides examples of some types of critical systems validation ground tests. Again these are *only examples* and should not be construed as the only types of ground tests which may be necessary to validate a specific system for a specific operational environment, nor should it be interpreted that all of these example ground tests will be necessary to validate a specific system.

Mechanical Systems and Components (Vehicle Structure, Pressurization, Propulsion System including engine frame thrust points, Ground Support Equipment)

- Types of Tests: Load, Vibration (dynamic and modal), Shock, Thermal, Acoustic, Hydro-static, Pressure, Leak, Fatigue, X-ray, Center of Gravity, Mass Properties, Moment of Inertia, Static Firing, Bruceton Ordnance, Balance, Test to Failure (simulating non-nominal flight conditions), Non-Destructive Inspections

Electrical/Electronic Systems (Electrical, Guidance, Tracking, Telemetry and Command, Flight Safety System (FSS), Ordnance, Flight Control and Recovery)

- Types of Tests: Functional, Power/Frequency Deviation, Thermal Vacuum, Vibration, Shock, Acceleration, X-ray, recovery under component failures, abort simulations, TDRSS integration testing (up to and including pre-launch testing with flight vehicle)

Propulsion Systems (Propulsion, FSS, Ordnance, Flight Control)

- Types of Tests: Simulation of nominal launch and abort sequences for engines (including restart, if applicable), Orbital Maneuvering System (including restart for reentry-burn) and Attitude Control System; Environmental testing (Thermal, Vibration, Shock, etc.)

Thermal Protection System

- Types of Tests (for TPS and bonding material): Thermal, Vibration, Humidity, Vacuum, Shock

Aerodynamics (Structure, Thermal, Recovery)

- Types of Tests: Wind Tunnel, Arc Jet, Drop Tests (Landing Systems)

Software (Electrical, Guidance, Tracking, Telemetry, Command, FSS, Ordnance, Flight Control and Recovery)

- Types of Tests: Functional, Fault Tolerance, Cycle Time, Simulation, Fault Response, Independent Verification and Validation, Timing, Voting Protocol,

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control the quality of both products and the processes that produce these products. For software product quality, the standard highlights four measures: specification, code reviews, software testing and measurements.

Abort sequences (flight and in-orbit) under non-nominal conditions with multiple system failures, Integrated Systems Tests

Flight Tests

Flight testing is very valuable to the space vehicle development process. As the RLVs complete engineering and safety analyses and ground testing, considerable planning is needed to define the flight test program that will establish the performance capabilities of the vehicle for routine and repetitive commercial operations. When flight testing is required, a flight test plan will be needed to demonstrate that the RLV's proposed method of operations is acceptable and will not be a hazard to the public's health, safety and safety of property.

The purpose of flight testing is to verify the system performance, validate the design, identify system deficiencies, and demonstrate safe operations. Experience repeatedly shows that while necessary and important, analyses and ground tests, cannot and do not uncover all potential safety issues associated with new launch systems. Even in circumstances where all known/identified safety critical functions can be exercised and validated on the ground, there is still the remaining concern with unrecognized or unknown interactions ("the unknown unknowns").

Flight tests should be conducted in a manner such that the vehicle and its instantaneous impact point never overfly populated areas. This permits the safe demonstration of the vehicle without posing a significant public safety hazard. The structure of the test program will identify the flight test framework and test objectives, establish the duration and extent of testing; identify the vehicle's critical systems, identify the data to be collected, and detail planned responses to nominal and unsatisfactory test results.

Test flight information includes verification of stability, controllability, and the proper functioning of the vehicle components throughout the planned sequence of events for the flight. All critical flight parameters should be recorded during flight. A post-flight comparative analysis of predicted versus actual test flight data is a crucial tool in validating safety critical performance. Below are examples of items from each test flight that may be needed to verify a reusable launch vehicle. Listed with each item are examples of what test-flight data should be monitored or recorded during the flight and assessed post-flight:

- Vehicle/stage launch phase: Stability and controllability during powered phase of flight.
  - Vehicle stage individual rocket motor ignition timing, updates on propellant flow rates, chamber temperature, chamber pressure, and burn duration, mixture ratio, thrust, specific impulse (ISP)
  - Vehicle stage trajectory data (vehicle position, velocity, altitudes and attitude rates, roll, pitch, yaw attitudes)
  - Vehicle stage Attitude, Guidance and Control system activities
  - Functional performance of the Vehicle Health Monitoring System
  - Functional performance of the Flight Safety System/Safe Abort System
  - Electrical power, and other critical consumables, usage and reserves (i.e. gases, fluids, etc…)
  - Actual thermal and vibroacoustic environment

  - Actual structural loads environment
- Staging/separation phase of boost and upper stages: Stable shutdown of engines, and nominal separation of the booster & upper stages.
  - Separation activity (timestamp, i.e., separation shock loads, and dynamics between stamps)
  - Functional performance of the Vehicle Health Monitoring System
  - Electrical power, and other critical consumables, usage and reserves (i.e. gases, fluids, etc…)
  - Functional performance of the Flight Safety System/Safe Abort System
- Booster stage turn-around (re-orientation) or “loft” maneuver phase (if applicable).
  - Rocket motor re-start (if applicable): timing, updates on propellant flow rates, chamber temperature, chamber pressure, burn duration, mixture ratio, thrust, ISP
  - Attitude, Guidance and Control system activities
  - Actual structural loads environment
  - Actual thermal and vibroacoustic environment
  - Functional performance of the Flight Safety System/Safe Abort System
- Booster stage flyback phase (if applicable): Flyback engine cut-off, fuel dump or vent (if required), nominal descent to the planned impact area, proper functioning and reliability of the RLV landing systems.
  - Booster stage post-separation (flyback) trajectory data
  - Electrical power usage and reserves
  - Booster stage landing system deployment activity (timestamp)
  - Actual thermal and vibroacoustic environment
  - Actual structural loads environment
  - Functional performance of the Vehicle Health Monitoring System
  - Functional performance of the Flight Safety System/Safe Abort System
  - Attitude, Guidance and Control system activities
- Vehicle stage ascent phase (if multistage): nominal ignition of the stage’s engine, stability and controllability of the stage during engine operation, orbital insertion – simulated (for suborbital) or actual – of the vehicle.
  - Vehicle individual rocket motor ignition timing, updates on propellant flow rates, chamber temperature, chamber pressure, and burn duration
  - Vehicle circularization and phasing burn activities (ignition timing, updates on propellant flow rates, chamber temperature, chamber pressure, and burn duration)
  - Vehicle trajectory data (vehicle position, altitude, velocity, roll, pitch, yaw attitudes at a minimum)

  - Attitude, guidance and control system activities
  - Functional performance of the Vehicle Health Monitoring System
  - Functional performance of the Flight Safety System/Safe Abort System
  - Electrical power, and other critical consumables, usage and reserves (i.e. gases, fluids, etc…)
  - Actual structural loads environment
  - Actual thermal and vibroacoustic environment
- Vehicle descent (including vehicle's de-orbit burn targeting and execution phases): Function of the programmed flight of the vehicle/upper stage to maintain the capability to land (if reusable) at the planned landing site, or to reenter for disposal (if expendable), assurance of fuel dump or depletion, and proper descent and navigation to the planned or alternate landing site.
  - Vehicle pre-deorbit burn trajectory data
  - Vehicle deorbit burn data (ignition timing, updates on propellant flow rate, chamber temperature, chamber pressure, and burn duration)
  - Vehicle descent trajectory data (position, velocity, and attitude)
  - Attitude, Guidance and Control system activities
  - Actual thermal and vibroacoustic environment
  - Actual structural loads environment
  - Functional performance of the Vehicle Health Monitoring System
  - Functional performance of the Flight Safety System/Safe Abort System
  - Electrical power and other critical consumables usage and reserves (i.e. gases, fluids, etc…)
  - Vehicle landing system deployment activity (timestamp)

Performance and Reliability Data

Performance and reliability data may be supported by flight history on other vehicles with similar or comparable safety critical systems, sub-systems, and components, and by conducting both analyses and tests, at the respective levels. Having a flight history could mean extensive documentation may not be required if it can be shown through test results, analyses, or empirical data, that the flight regimes experienced are similar to the proposed flight regime. The degree of applicability of data depends on the degree of similarity to environmental conditions and how environmental conditions compare to the history and anticipated reactions of this system. Even when the same system, sub-system, or component is known to have an extensive (and favorable) flight history in the same or more severe environments, interfaces and integration with other systems would still be examined and tested. Another method of acquiring data is through estimating system, sub-system, and component 3-sigma performance and reliability numbers from testing evaluations and (where applicable) flight data.

The use of similarity is not new to launch operations. EWR 127-1, para. 4.14.1.2, states: as required, qualification by similarity analysis shall be performed; if qualification by similarity is not approved, then qualification testing shall be performed. For example, if component A is to be considered as a candidate for qualification by similarity to a component B that has already been qualified for use, component A shall have to be a minor variation of component B. Dissimilarities shall require understanding and evaluation in terms of weight, mechanical configuration, thermal effects, and dynamic response. Also, the environments encountered by component B during its qualification or flight history shall have to be equal to or more severe than the qualification environments intended for component A.

Operational Controls

There is an interrelationship between the system design capabilities and the systems operational limitations. Figure 3 depicts the relationship between the vehicle systems and the scope of operations within which the vehicle is operated. What constitutes a safety critical system may depend on the scope and nature of the vehicle design and its proposed operations. Intended operational requirements affect the proposed vehicle design requirements and vehicle capabilities/limitations and also establish the operational system constraints necessary to protect public health and safety. For example, landing sites may have to be within some minimum cross-range distance from the orbital ground trace because of cross-range limitations of the vehicle. A vehicle operator may choose, or be required, to mitigate certain vehicle limitations through the use of operational controls rather than relieving vehicle limitations through design changes.

Test parameters and analytic assumptions will further define the limits of flight operations. The scope of the analyses and environmental tests, for example, will constitute the dimensions of the applicant's demonstration process and therefore define the limits of approved operations if a license is issued. Such testing limits, identified system and subsystem limits, and analyses also are expected to be reflected in mission monitoring and mission rules addressing such aspects as commit to launch, flight abort, and commit to reentry.

Vehicle capabilities/limitations and operational factors such as launch location and flight path each affect public risks. The completion of system operation demonstrations, such as flight simulations and controlled flight tests, provide additional confidence in the vehicle systems and performance capabilities. As confidence in the systems overall operational safety performance increases, key operational constraints such as restrictions on overflight of populated areas may be relaxed.

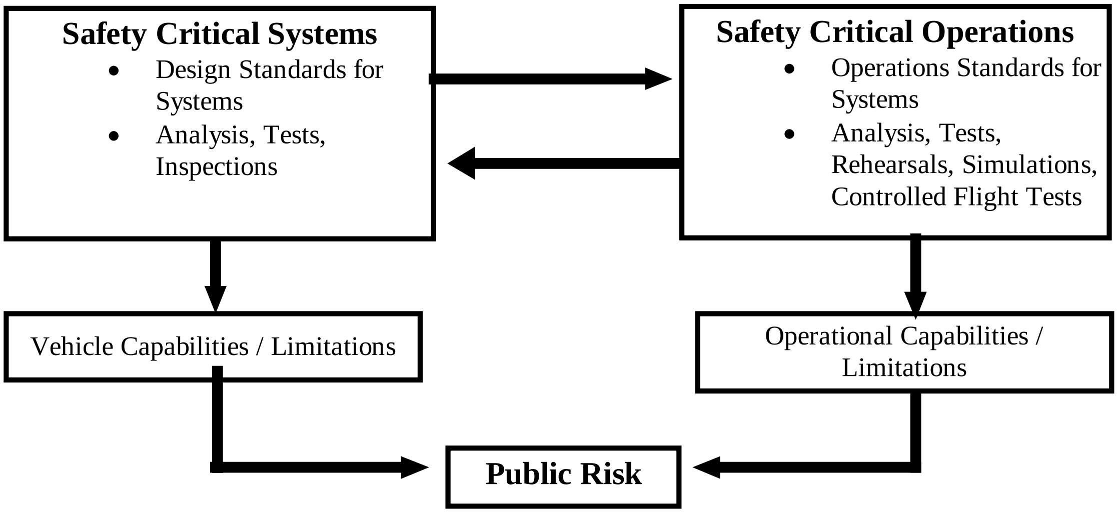

FIGURE 3: INTERRELATIONSHIP BETWEEN SAFETY CRITICAL SYSTEMS AND OPERATIONS

The following are examples of the types of operations-related considerations that may need to be addressed by the applicant when establishing their operations scenarios.

- Launch commit criteria/rules
- Human override capability to initiate safe abort during launch and reentry
- System monitoring, inspection and checkout procedures
- For reflight: inspection and maintenance
- Selected primary and alternate landing sites for each stage
- Surveillance/control of landing areas
- Standard limits on weather
- Coordination with appropriate air space authorities
- Limits on flight regime (ties in with analysis, testing and demonstrating confidence in system performance and reliability)
- Limits on over-fight of populated areas
- Others identified through hazard analysis

Objective 3: Human Intervention Capability During the Ascent To Orbit Phase for Orbital Missions, and throughout the entire mission (ascent and descent), for Sub-orbital Launches of Reusable Launch Vehicles

Risks to the public from non-nominal launches should be mitigated through control based on human decision making or intervention in addition to any on-board automatic abort system. The specific flight safety systems design involving ground, airborne or on-board capability should assure the redundant ability to initiate a safe abort of a malfunctioning RLV.

Discussion:

ELVs and conventional aircraft incorporate human decision making in conjunction with on-board automatic systems to ensure public safety if a non-nominal event regarding the vehicle occurs. Most ELV safety systems have over 40 years of operational history and proven reliability and are relatively simple in design. The majority of ELV safety systems are destructive (explosive) and are designed to be used over unpopulated areas such as broad ocean areas where the vehicle debris impacts do not affect public health and safety. However, most RLV safety systems will not have the benefit of low operating risk and high confidence levels associated with the experience and flight history of ELV Flight Termination Systems. Without considerable testing, including flight tests, it may be difficult to establish autonomous RLV Flight Safety System reliability with adequate confidence to permit overflight of populated areas. These sophisticated RLV safety systems may be expected to monitor and address a myriad of possible systems failures. The RLV safety system will be required to respond appropriately to these system failures and provide a level of public safety that is at least equivalent to the level of public safety provided by ELV safety systems. Providing human control, at least through an override capability to the RLV safety system, should lower that system's operational risk. Therefore, a human operator should have the ability to monitor the status of the vehicle during ascent and at other critical times (as per. Objective 5) in order to independently initiate abort actions should it be necessary.

Objective 4: Positive Human Initiation of Reentry Activities

Risks to the public from non-nominal reentries should be mitigated through control based on human enable of the reentry activity. This objective is intended to provide fail-safe assurance that reentry activities cannot be initiated prior to human verification that all pre-reentry readiness activities, including verifying the configuration and status of reentry safety critical systems.

Discussion:

Depending on system design and operations concepts, it is anticipated that there will be a number of activities that will need to be completed, prior to the initiation of reentry operations, to assure that a reentering vehicle will not pose significant risks to the public. These activities may include clearing airspace in the reentry corridor, securing reentry-landing sites, verifying the configuration and status of reentry safety critical vehicle systems, verifying reentry corridor weather is within vehicle operational constraints, etc.

Some of these activities are independent of the vehicle systems and as a result autonomous control systems would not consider them. Therefore, a human operator should have the ability to monitor the status of the vehicle reentry safety critical systems prior to initiating reentry operations.

Objective 5: Flight Data Monitoring and Recording

The RLV and ground support systems should provide for sufficient flight data monitoring such that the status of key systems is provided during the entire launch phase of the mission and at the other safety critical mission decision points. This may be done through telemetry, in real time, to a control center which has command capability and decision making responsibility. Other data that is not essential to be monitored in real time but for which monitoring or verification is necessary for system validation, system reuse, performance characterization, etc., could be recorded onboard for non-real time download or retrieval post-mission.

Discussion:

In order to provide the human intervention capability during the launch phase as described in objective 3, and the fail safe enable of reentry operations as described in objective 4, a level of flight data monitoring would be necessary. The specifics of which data will need to be monitored and when it will need to be available will be dependent on vehicle systems and operating concepts. In addition, the whole premise of RLV vehicles is reusability of the vehicle and the premise of flight tests is to learn more about the performance of the on-board systems and the actual operating environment. Such data is critical to providing the confidence needed to expand the test flight envelope, and could be gathered and provided via telemetry for review and analysis while the vehicle is still in flight or retrieved post flight. Regarding real time and non-real time (down-loading stored data) telemetry, the categories fall into information that is crucial for determining vehicle safety and performance status (real time), and information which is compiled by the vehicle for which there is no requirement for immediate (real time) access (thus non-real time would be acceptable).

Objective 6: Non-nominal Reentry Risk Mitigation

RLVs designed to re-enter from orbit and survive substantially intact should not produce a total public casualty expectancy (E_C) greater than $30x10^{-6}$ as a result of nominal or non-nominal launch and reentry operations.

Discussion:

All things placed into earth orbit will eventually reenter the earth's atmosphere[14]. This is because their orbits decay due to a number of factors including atmospheric drag and

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[14] Anything placed in earth orbit will eventually decay. All orbiting objects have some rate of decay, not just LEO but up to and including Geo-Synchronous Orbits (GEO).

magnetic forces. The length of time it takes depends on the size of the object and the altitude and eccentricity of the orbit. Generally, the lower the orbit, the less time it takes for the object to decay out of orbit. Normally, spacecraft and launch vehicle stages inserted into orbit are not designed to survive reentry and all, or nearly all, of their components are vaporized before impacting the earth because of the high temperatures encountered as they pass through the atmosphere. RLV reentry stages that are protected from these high temperatures for recovery, may survive a non-nominal or random reentry intact unless preventive measures are taken.

After reaching orbit, if a decision is made that commanded reentry towards the landing site will not be attempted, the vehicle will eventually reenter randomly as the vehicles orbit naturally decays, unless a commanded reentry is performed for the purpose of disposing of the vehicle in a remote ocean area. The intent of this objective is to ensure reentering RLV bodies pose no more risk[15] than other stages and payloads that reenter and, if necessary, can be completely destroyed by normal reentry heating and loads.

This objective allows for the use of planned sites which may include alternate sites, such as a broad ocean area, when circumstances are such that while reentry can be initiated, there is not sufficient controllability to land in a relatively small area because of system failures or other detected degradation of system performance.

Incorporating the ability to destroy the heat shield effectiveness in a random reentry condition may also satisfy this objective. That is, provide for the ability to significantly mitigate the risk under the circumstances of a random reentry situation by disabling or otherwise compromising the effectiveness of the thermal protection system (TPS). Aside from destructing the vehicle during reentry, some limited type of action may be sufficient to breach a portion of the TPS of the vehicle. Its integrity compromised, the vehicle would burn up upon reentry. Such actions may include consideration of opening payload compartment doors, reorienting the vehicle attitude, breaching, removing or otherwise rendering key areas of the TPS ineffective.

Objective 7: Overflight of Populated Areas

RLV flight over land corridors should be selected such that any land overflight avoids densely populated areas. Determinations of population densities for such areas are based on a density that is dependent on the casualty area from each RLV configuration, and may differ for each case.

Discussion:

RLVs by their very nature are experimental, utilize unproven systems and operating concepts, and have the potential for catastrophic failures that could negate their ability to abort safely.

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[15] During the approval process for the COMET/METEOR reentry vehicle, one of the safety issues addressed by the DOT was the risk to the public if the decision was made, because of system problems, to not attempt a reentry. In this case the reentry vehicle's debris (even if the vehicle survived completely after its orbit decayed), was less than that believed to survive from many ELV stages. This may not be the case for RLVs because of their size.

The intent of this objective is to limit the potential of a catastrophic consequence involving a potentially large number of public casualties, even though the computed risk of such an occurrence may be much lower than the risk objective[16]. This standard is similar to the restrictions placed on experimental aircraft and aircraft flight testing.

Consideration has been given to establishing a fixed population density value; however, assigning such a value may be inappropriate because there are many configurations and sizes of proposed RLVs. Population density limits would be dependent on the casualty area from each RLV configuration, and therefore would differ for each case. Each RLV configuration would thus be evaluated for its maximum probable impact in a non-nominal situation. That maximum probable impact data would then be used along with the Ec requirement to solve for the maximum allowable population density for overflight. Each vehicle would therefore have a different overflight constraint.

Objective 8: Reentry/Landing Site Risks

The public located in proximate vicinity to the planned reentry site should not be exposed to an unreasonable risk as a result of RLV operations. For nominal missions, the predicted 3-sigma dispersion of a RLV reentry vehicle during descent (landing) operations will be wholly contained within the planned landing site.

Additionally, it is a goal that the risks to the public from such a nominal reentry shall not exceed an E_C of $1x10^{-6}$ for areas surrounding the site.[17]

Discussion:

Reentry systems must land at designated locations and the size of the landing sites must be sufficient to accommodate the characteristics of the vehicle. Depending on the vehicle and its capability to adjust its landing point and the accuracy of the landing systems, the size of the landing footprint can vary. It is the intent of this objective to ensure that, for nominal operations, the 3-sigma landing footprint of the vehicle be contained within the controlled landing site.

This objective is based on nominal performance of the vehicle and does not include the impacts of system failures. It is directed at the nominal flight capabilities of the vehicle and the demonstration that the controlled landing site is of sufficient size to accommodate the vehicle. (The possible impacts of system failures during reentry operations will be addressed in the reentry Expected Casualty analysis.) This objective does not impose severe restraints on reentry site selection unless the reentry dispersion is large.

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[16] If the collective risk for the mission has an expected casualty of 30×10^{-6}, the risk of 30 casualties occurring in a single event, for example, will be far less, approximately 1×10^{-7}.

[17] For example: In COMET/METEOR, the surrounding area was defined as that area within 100 miles of the landing site.

Objective 9: Preplanned, Pre-approved Staging Impact Points, Contingency Landing Sites and Contingency Abort Sites

For launch and reentry operations, RLV operators would provide staging impact points and, at selected points along its overflight corridor, safe, pre-planned, pre-approved[18] contingency abort landing sites. These sites must be large enough to ensure that all RLV landing hazards are contained within the designated site. There should be a sufficient number and distribution of such sites to assure abort to these sites (or to orbit) can be achieved from any phase of the flight. These sites should avoid air traffic routes or mitigation measures could be taken to ensure there are no aircraft over the site at the time of reentry.

Discussion:

Conventional aircraft are operated in a manner that requires the aircraft to abort the flight and land at the nearest suitable airport whenever critical flight safety systems malfunction. Expendable Launch Vehicles (ELV) currently operate primarily over broad ocean areas only sparsely populated by shipping. The current practice is to contain a malfunctioning ELV within these broad ocean areas through the use of both on-board automatic and ground commanded systems. Similarly, continuing flight of a malfunctioning RLV may not be permitted. An abort executed to a safe landing site may be necessary just as it is for conventional aircraft. One of the major risk mitigation attributes of RLVs is that should a malfunction occur and the event is not a catastrophic failure, the vehicle will abort the flight allowing the recovery of the vehicle and payload intact while not endangering the public.[19] Therefore, it may be prudent to provide the (contingency) capability to safely abort to a landing site and to ensure that the landing site can safely accommodate the vehicle.

Just as occurs for ELV launches, RLVs will need to establish exclusion areas for aircraft. Such areas are monitored and should an aircraft be within the area, the launch and/or reentry is delayed until the area is clear. Another risk mitigation technique is the issuance of notices for stage impact areas. In the case of RLVs such actions are appropriate for launches as well as the planned, primary and alternate, landing sites.

Objective 10: Flight Test Demonstration Program

Inland populations should not be exposed to unreasonable risk of harm from unproven RLV systems.

RLVs that are intended to operate from inland sites involving substantial overflight of populated areas to achieve their mission, should perform a flight test

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[18] "Approval" refers to any approval by the FAA with respect to the proposed sites meeting the requirements otherwise stated in this (or similar document) as well as any other state and local entities that may have regulations covering the use of such sites.

[19] At some stage in the flight the vehicle may also safely abort to orbit before attempting a reentry to a landing site. The number of sites will depend on the vehicle's capabilities but may include the launch site as well as one or more down range sites.

demonstration program.[20] Test flights can demonstrate that the RLV can perform the critical abort and recovery maneuvers necessary to fly safely over populated areas. Flight test demonstrations would be conducted over unpopulated areas or over areas so sparsely populated that the acceptable risk levels of $E_C < 30x10^{-6}$ can be achieved assuming a probability of failure = 1 while over the populated area.
Discussion:

Flight testing is typically performed in order to learn more about system performance and implies a higher level of uncertainty and potential for a failure. There are ways of conducting flight tests to ensure that the public is not exposed above a minimum safety threshold. New ELVs conduct their first flights at ranges where the ability to contain the adverse effects of a malfunctioning vehicle is ensured such that the effect will not reach public areas. RLVs which want to eventually operate for some period over populated areas from lift-off to orbital insertion or from de-orbit through landing, may be required to perform flight demonstration tests to ensure public safety. The extent of such RLV test flights (e.g., suborbital or orbital) will depend on the ability to contain and limit exposure to the specified limit.[21] Most RLVs propose to operate over populated areas, and are relying heavily on Flight Safety Systems to provide a (contingency) safe abort capability to achieve required safety levels. The performance and reliability of such flight safety systems, as well as other systems, become an important element to safety demonstrations. It is very unlikely that sufficient confidence in such system's performance and reliability can be achieved solely through analysis and ground tests. Therefore, it may be necessary that part of the demonstration process include controlled flight tests. Because flight testing is part of the demonstration process to verify the performance and capabilities of safety critical systems, is it important, given the limited confidence prior to such tests of new, unproven vehicles, that flight tests be conducted at a reduced collective risk level. (i.e. $E_C < 30 \times 10^{-6}$ using a probability of failure = 1)
For example, for a vehicle with a casualty area of 5,000 square feet, that would effectively limit the areas exposed to a population density of less than 0.16 people per square mile.

Unlike aircraft, where there have been hundreds of thousands of aircraft systems (e.g., jet turbine engines) produced and flown, this is not the case for the proposed reusable launch vehicles. New aircraft typically go through a flight test program during which the functioning and performance of the aircraft and systems are checked out in a flight environment *before* they are permitted to fly over densely populated areas.

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[20] More stringent safety operational standards may be appropriate to allow the first test flight to be orbital. For example conditions, such as oceanic reentry, may apply. Initial test flights not involving overflights of populated areas (e.g., coastal-over water or suborbital - within the confines of an unpopulated area) may be permitted, if it can be demonstrated that the vehicle will stay within the confines of the unpopulated area at all times. An example may be the utilization of a flight termination system and predefined destruct lines such that it prevents the vehicle/debris instantaneous impact point (IIP) from passing over populated areas..

[21] There may be circumstances where the intent of the proposed objective for test demonstration flights is clearly achieved without such tests. The nature of such conditions is not clearly defined and would be based on the specific circumstances including the population exposed, the degree of analyses and other testing conducted and the confidence that could be placed in such demonstrations. These circumstances would be addressed on a case-by-case basis.

While many of the major systems of an RLV may be unique, it is often the case that such systems are created using subsystems and components for which there is some performance and reliability experience. The usefulness of such information is dependent on whether the experience is associated with similar environments and operational profiles. In addition, there may be issues associated with the interfaces and interactions between subsystems/components.

While many tests can be conducted on a system level on the ground (e.g., much like turbine engine test stands for testing aircraft engines after a major overhaul), it may be necessary to conduct RLV flight tests in order to test all the systems and their interactions in a flight environment.

The FAA may consider licensing a sequence or series of test flights as long as the flight test operations are maintained within an envelope of approved parameters.

Objective 11: Preflight Inspection and Checkout

Prior to each flight, RLVs should undergo system monitoring, inspection and checkout to ensure that all critical systems are functioning within intended parameters and are not otherwise impaired or degraded.

Discussion:

Due to the inherent risks of operating RLV's, it is necessary to verify that all launch and reentry safety critical systems are functioning properly prior to launch. This type of pre-operations verification and checkout has been a standard practice in the aircraft and space launch industries since their inception. Even for test flights, it is important for safety to ensure the systems are functioning properly before each flight. The purpose of test flights is to demonstrate and measure the performance and functioning of key systems. Such information may not be of great value if the condition of the system being tested is not clear. Such information will provide valuable documentation on how the critical systems hold up to the flight environment and the cycling of loads on the vehicle due to reusability. Unanticipated problems may be uncovered during this process which, if not corrected, might lead to serious public health and safety consequences. The vehicle developer and operator should define a preflight validation and checkout process/procedure that meets the intent of this objective.