SCI 236 AGARDograph
Part Two
National Aeronautics and Space Administration
Armstrong Flight Research Center Annex

1. Organization

1.1. Title

National Aeronautics and Space Administration (NASA) Armstrong Flight Research Center (AFRC)

1.2. Location

Edwards Air Force Base, Edwards, CA and United States Air Force (USAF) Plant 42, Palmdale, CA

1.3. Nature of Flight Test Activity

NASA AFRC is a United States government entity that conducts the integration and operation of new and unproven technologies into proven flight vehicles as well as the flight test of one-of-a-kind experimental aircraft. AFRC also maintains and operates several platform aircraft that allow the integration of a wide range of sensors to conduct airborne remote sensing, science observations and airborne infrared astronomy. To support these types of operations AFRC has the organization, facilities and tools to support the experimental flight test of unique vehicles and conduct airborne sensing/observing.. The current aircraft fleet encompasses a wide range of aircraft, including remotely piloted and autonomous vehicles and consists of:

- **F-18A/B**
- **F-15B/D**
- **T-34C**
- **TG-14**
- **G-III**
- **B-200 (KingAir)**
- **DC-8**
- **B-747SP**
- **ER-2**
- **RQ-4**
- **MQ-9**
- **Wide range of small Unmanned Aircraft Systems (UAS)**

2. Background

AFRC was originally established in 1946 as the High Speed Flight Research Station. A contingent of engineers, pilots, maintainers and administrative support personnel were deployed to Muroc Army Air Base (now Edwards Air Force Base) from the National Advisory Committee for Aeronautics Langley Memorial Aeronautical Laboratory to support the first supersonic research flights of the X-1 rocket-powered aircraft. The organization grew and expanded its capabilities over the years as it continued to support the development of and research associated with aerospace research vehicles. The staff currently consists of 535 civil servants and approximately 600 contractor personnel. In 2006, AFRC established a long-term lease with Los Angeles World Airports for Building 703 located adjacent to USAF Plant 42 (Palmdale Airport). The majority of the airborne remote sensing and airborne astronomy is accomplished from this facility. Through agreements with the US Department of Defense (DOD), AFRC maintains access to the airfields and airspace that allows the conduct of a full range of aeronautical flight research and test from both locations. Dryden Aeronautical Test Range (DATR) supplies a comprehensive set of resources for the control and monitoring of flight activities, real-time acquisition and reduction of research data, and effective communication of information to flight and ground crews.

3. Regulatory Framework

3.1. External

3.1.1. NASA has been granted the authority by US Federal legislation to provide airworthiness certification, outside of the Federal Aviation Administration (FAA) and DOD systems, for all aircraft and UAS operated under its purview. The NASA airworthiness certification process provides the opportunity to conduct flight operations both domestically and internationally

3.1.2. It is a requirement of NASA Headquarters that the Center maintain a Quality Management System. AFRC's Quality Management System is certified through the AS9100 quality system requirements.

3.2. Internal

To provide airworthiness certifications and review of flight test activities, the Center has developed a robust airworthiness and flight safety review process. AFRC processes used to support flight test and safety activities satisfy the AS9100 requirements. The overarching guidance document is AFG-7900.3-001, Airworthiness and Flight Safety Review, Independent Review, Technical Brief, and Mini-Tech Brief.

3.3. Flight Test Policy

NASA policy, as codified in NPR7900.3 Aircraft Operations Management, states:

3.3.1. For each Center operating aircraft/UAS or procuring and/or acquiring aircraft/UAS services, the Center Director shall maintain a program-independent Flight Operations Office, the specific purpose of which will be to plan, organize, direct, and control the operations, maintenance, modification, safety, and support of all Center-assigned or -contracted aircraft.

3.3.2. The Center Director shall assign the Chief of the Flight Operations Office the authority and responsibility and provide the resources necessary to manage and conduct safe, effective, and efficient operations in accordance with NASA directives, guidance, and other applicable Federal regulations.

3.3.3. Center Directors shall be responsible for the airworthiness and flight safety of all Center-assigned aircraft and UAS, including commercial aircraft services.

4. Flight Test Safety Management System

AFRC has implemented this policy through a matrix management system of Project Managers, Engineering, and Flight Operations, with Safety and Mission Assurance providing an independent assessment and support to the project team. The Center Director has also established the position of Center Chief Engineer who is the independent authority for airworthiness, flight safety and mission success. Long established Center practice has demonstrated that safe flight research results from an effective leadership team consisting of a Project Manager, a Project Chief Engineer (typically from the Research Engineering Directorate) and an Operations Engineer from the Flight Operations Directorate. The focus of the Project Manager is leadership of the team and responsibility for schedule and financial resources. The Project Chief Engineer provides leadership for the engineering team and the focus on the research aspects. The Operations Engineer is responsible for aircraft airworthiness and is the interface with the hands-on workforce in the Flight Operations Directorate. In total, this team owns the responsibility for the assessment of risks, identification of mitigations, and implementation of these mitigations. The Safety and Mission Assurance Directorate is a partner in this process, but also functions as an independent authority. The risk/hazard evaluation process is described in Section 6. This team is also responsible for Mission Success. AFRC's Senior Leadership (Center Director and Directorate Chiefs) is engaged as described in Section 6. This implementation allows a small Center to manage and execute the broad portfolio of work described in Section 1.

5. Organization and People

5.1. Research and Engineering Directorate

This organization is responsible for performing the research and engineering tasks necessary to safely and successfully accomplish the Center's flight research and test mission. The Directorate is organized with seven Branches addressing key engineering disciplines: Systems Engineering and Integration, Aerodynamics and Propulsion, Dynamics and Control, Advanced Systems Development, Flight Instrumentation and Systems Integration, Aerostructures, and Research Engineering Operations

5.2. Flight Operations Directorate

This organization fabricates, maintains, modifies and instruments aircraft and flight test articles, ensures airworthiness/flight readiness and safely flies them in a precise manner to required test points in order to deliver highest quality data to the customer. The Branches in this organization include: Flight Crew Branch, Operations Engineering Branch, Avionics and Instrumentation Branch, Fabrication Branch, Life Support Branch, Maintenance Branch, Aircraft Records Branch, and Engineering Support Branch.

5.3. Mission Operations Directorate

This Directorate provides effective and efficient Simulation, Range and IT solutions. The Dryden Aeronautical Test Range (DATR) supplies a comprehensive set of resources for the control and monitoring of flight activities, real-time acquisition and reduction of research data, and effective communication of information to flight and ground crews. The primary services provided for safety and risk management are the aircraft simulations and the services and capabilities of the Dryden Aeronautical Test Range.

5.4. Safety & Mission Assurance Directorate

The mission of this directorate is to ensure safe operations and mission success while understanding and mitigating risks to the public, property and mission. In addition, S&MA ensures a safe and healthy work place for employees and visitors. The Branches in this organization are: Quality Assurance Branch, Safety and Environmental Branch, Flight Research and Test Safety Branch.

5.5. Programs and Projects Directorate

This Directorate leads and manages Center Project and subproject activity, providing the Project Management and Program Planning and Control functions.

5.6. Mission Support Directorate

This Directorate provides the Facilities infrastructure support, Protective Services, and Procurement functions that enable all of the Center's flight test and operations activities.

6. Process and Procedure

6.1. Flight Test Safety Review Process

Over the past 70+ years AFRC has developed an airworthiness and flight safety review process that provides an efficient way to review and approve vehicle airworthiness while ensuring a high probability of safe operations for the flight test of unique aerospace technologies and vehicle configurations. This single process can be tailored to address the airworthiness and safety review of a wide variety of flight test activities, manned as well as unmanned. A risk and hazard management based approach is applied that promotes the safe and successful execution of high risk flight tests. It assesses, communicates and accepts the residual risks inherent in the operation and test of unique flight vehicles.

6.2. Airworthiness and Flight Safety Review Process

6.2.1. Boards

Flight test activities are reviewed and approved for flight by independent review boards.

6.2.1.1. Airworthiness and Flight Safety Review Board

The Airworthiness and Flight Safety Review Board (AFSRB) is a standing board of Armstrong senior leadership (Research and Engineering Director, Flight Operations Director, Mission Systems Director, Safety and Mission Assurance Director, Programs and Projects Director) chaired by the Center Chief Engineer who deliberate on the material presented and formulate a consensus-based recommendation to the Center Director regarding the project's readiness for flight and the acceptability of residual risk. This Board is augmented by the Chief Test Pilot and the Aviation Safety Officer for piloted tests and the Range Safety Officer for UAS activities.

6.2.1.2. Flight Readiness Review Board

The Flight Readiness Review Board (FRRB) is an ad hoc group of subject matter experts fully independent of the project under review. The board is chartered by the Center Chief Engineer to conduct an independent review and assessment of the entire project and ensure that proper, adequate planning and preparation have been accomplished resulting in the project being conducted in an acceptable safe manner. The FFRB verifies that the System Safety Plan has been followed and that all analyses and results have been properly documented by the project team. They can also be charged with assessing the ability of the project to achieve mission success. They ensure that all identifiable risks have been documented, assessed, and are adequately controlled or properly identified as accepted risks. A key element of the review at this level is constant communication between the FRRB, the project team and Center management. In addition to maintaining awareness, this allows issues to be worked early at the correct level. The FFRB assesses the approach and implementation in regard to public, ground, flight, and range safety and examines the project generated hazard analyses in detail, verifying that proper mitigations have been implemented and that reasonable residual risk has been identified. If deemed necessary for their assessment the FRRB may conduct independent analysis or simulations to compare with project generated results. They present their findings and recommendations to the AFSRB.

6.2.1.3. Technical Briefing Board

A standing board of Armstrong senior managers chaired by the Center Chief Engineer who provide a final series of peer reviews of the project's plans and preparations through the execution of the project. The Technical Briefing, or Tech Brief, is one of the more important tools used by the Center to ensure the safe and efficient conduct of the flight test mission. Its major function is to continue the review process after the AFSRB has made its final recommendations and a program moves into the flight or test phase. There are two primary purposes for holding Tech Briefs. First, the individual Project Office is given the opportunity to present its goals and plans to a group of peers. These peers represent all the various disciplines at Center, with special emphasis on the particular areas of interest that are being explored during the proposed flight tests. A Project, in this way, receives the benefit of the experience and expertise of projects conducted previously. The peer review, using past experiences, is a proven way of bringing overlooked items to light. The second purpose of Tech Briefs is to present a current assessment of Project risks to the Center management team. It allows management to reconsider its understanding of the risks involved prior to each flight. This helps ensure that any risks that cannot be eliminated or reduced will be accepted at the appropriate level of authority and responsibility. The Tech Brief review should also address the data analysis results from previous flights of the aircraft with particular emphasis on envelope expansions or any unexpected results, and whether or not they are expected to present problems during future tests. These results should provide a smooth transition to the objectives of the proposed flight plan.

6.2.2. Level of Review

Early in a project's life cycle the chair of the AFRC Airworthiness and Flight

Safety Review Board (AFSRB) works with the project team and Center management to determine the appropriate level of independent review required. The level of review is based upon factors such as complexity, criticality, visibility and level of residual risk. Four review levels are available:

6.2.2.1. Chief Engineer Review

For low risk, simple, non-critical tests the Center Chief Engineer, as AFSRB chair, may solely review the project team's plans and preparations for adequacy for performance of the proposed operation with the necessary level of safety and clear it for flight.

6.2.2.2. Chief Engineer with subject matter experts

The next level of review is conducted by the Center Chief Engineer with a small team (2-4 people) of subject matter experts who review the project team's plans and preparations for adequacy with the necessary level of safety and clear it for flight with a Technical Briefing.

6.2.2.3. Airworthiness and Flight Safety Board Review

The next higher level of review is conducted by the full AFSRB. The project team presents their plans and preparations to the entire AFSRB who determine whether the project had integrated appropriate flight safety and adequately assessed the residual risk of conducting the test. The Board presents their recommendation as to the project's readiness to proceed to flight and the residual risk stance to the AFRC Director who either concurs or non-concurs with the AFSRBs recommendation for the project to flight. Final flight approval is provided through a Technical Briefing

6.2.2.4. Flight Readiness Review Board Review

The most rigorous level of review is conducted by a Flight Readiness Review Board who assesses the project's plans, preparations and residual risk position and whether they have adequately integrated flight safety. The FRRB presents their assessment, findings and recommendations to the AFSRB who determine whether the project should proceed to flight. The AFSRB presents their recommendation and the residual risk stance to the AFRC Director who either concurs or non-concurs with the AFSRBs recommendation for the project to flight. Final flight approval is provided through a Technical Briefing

6.2.3. Hazard Evaluation and Communication

6.2.3.1. Hazard Review

Hazard analysis and review is conducted throughout a project's life cycle. Hazard analysis and report generation are conducted by the project's system safety working group typically made up of the project's lead for safety, chief engineer, operations engineer, pilot, and project manager. Hazard reviews are conducted by each review board held for system engineering and airworthiness and flight safety reviews.

6.2.3.2. Residual Risk

Experimental flight often carries higher risk than operational flight. After all appropriate mitigations have been accomplished the residual safety and technical risks are documented, reviewed and communicated through the system engineering and airworthiness and flight safety reviews.

6.2.3.3. Hazard Matrix

There are two Center residual risk hazard action matrices (HAMs) that serve as the primary means of communicating safety hazard management classification. The purpose of these templates is to relate human safety hazards, loss of high-dollar value assets, and/or loss of mission in terms of the hazard's severity and its probability in order to identify the associated overall hazard risk. The HAMs identify the level of management approval required for actual acceptance of risks (accepted risks) by the solid red and red cross-hatched areas on the HAMs. The HAM instructions reflect the accepted, Center wording for hazard probability and severity classifications of mishap occurrence. Projects will not change the substance of the HAM presentation if it is planned for use as part of the Center airworthiness process without an approved waiver. Final hazard classifications are determined after the project or program has exhausted all planned corrective and controlling actions utilizing the Hazard Mitigation.

6.2.3.3.1. Hazard Probability

The probability categories are derived from NPR 8715.3, NASA General Safety Program Requirements. “Probability is the likelihood that an identified hazard will result in a mishap, based on an assessment of such factors as location, exposure in terms of cycles or hours of operation, and affected population.” The probability is based on the scope and duration of the risk being assessed and presented to Center management. The probability is determined by quantification (analysis/calculated), or by qualitative means with appropriate justification (clear rationale) for the assessment. The Hazard Probability categories are:

- **Frequent** – Likely to occur immediately OR expected to occur often in the life of the project/item. Controls cannot be established to mitigate the risk.

- **Probable** – Probably will occur OR will occur several times in the life of a project/item. Controls have significant limitations or uncertainties.
- **Occasional** – May occur OR expected to occur sometime in the life of a project/item, but multiple occurrences are unlikely. Controls have moderate limitations or uncertainties.
- **Remote** – Unlikely but possible to occur OR unlikely to occur in the life of the project/item, but still possible. Controls have minor limitations or uncertainties.
- **Improbable** – Improbable to occur OR occurrence theoretically possible, but such an occurrence is far outside the operational envelope. Typically robust hardware/software, operational safeguards, and/or strong controls are put in place with mitigation actions to reduce risk from a higher level to an improbable state.

6.2.3.3.2. HAZARD SEVERITY

Severity can be broken out into personal injury or loss of asset/mission. Personal injury can be broadened to include death, disability, illness, and several categorizations of injury (life threatening, lost-time, minor, etc.). Loss of asset/mission can be broadened to include loss of system, substantial system damage, minor system damage, property damage, and loss or compromise of mission (incomplete mission success). The Human Safety Hazard Severity categories are:

CLASS I (CATASTROPHIC)	A condition that may cause death or permanently disabling/life-threatening injury.
CLASS II (CRITICAL)	A condition that may cause severe/lost time injury or occupational illness.
CLASS III (MODERATE)	A condition that may cause medical treatment for a minor injury or occupational illness (no lost time).
CLASS IV (NEGLIGIBLE)	A condition that could cause the need for minor first aid treatment (though would not adversely affect personal safety or health).

The Loss of Asset/Mission Hazard Severity Categories are:

CLASS I (CATASTROPHIC)	Total direct cost of mission failure and property damage of $2M or more, ***OR*** Crewed aircraft hull loss, ***OR*** Unexpected aircraft departure from controlled flight for all aircraft except when departure from controlled flight has been pre-briefed.
CLASS II (CRITICAL)	Total direct cost of mission failure and property damage of at least $500k, but less than $2M.
CLASS III (MODERATE)	Total direct cost of mission failure and property damage of at least $50k, but less than $500k.
CLASS IV (NEGLIGIBLE)	Total direct cost of mission failure and property damage of at least $20k, but less than $50k

7. Facilities and Tools

7.1. Flight Loads Laboratory (FLL)

The FLL was constructed in 1964 as a unique national lab to support flight research and aircraft structures testing. FLL personnel conduct mechanical-load and thermal test of structural components and complete flight vehicles in addition to performing calibration tests of vehicle instrumentation ofr real-time determination of flight loads. Mechanical loads and thermal conditions can be applied either separately or simultaneously to simulate combined thermal-mechanical load conditions. FLL personnel also conduct modal survey and structural mode interaction testing to support structures research and assess aircraft for flutter airworthiness.

The FLL staff have expertise in ground and flight test design and operations: load, stress, dynamic and thermal analysis; and instrumentation and measurement systems development. This expertise, coupled with a large array of capital equipment and advanced data acquisition and control systems, make the FLL and ideal laboratory for research and testing of aerospace vehicles and structures flying in the subsonic through hypersonic flight regimes.

7.2. Research Aircraft Integration Facility

AFRC maintains a simulation engineering capability that is focused on providing high fidelity fixed-base aerospace vehicle simulations that support research from concept through flight test phases of activity. This capability consists of batch, pilot-in-the-loop and full hardware-in-the-loop simulations. Where necessary, ground assets may be extended to remotely piloted vehicles and distributed environments that have combinations of real and simulated vehicles, or combinations of real and simulated components.

7.3. Experimental Fabrication and Repair Shop

The AFRC Experimental Fabrication Branch is a one-stop manufacturing, modification, and repair center that can assist a project from initial design through assembly and installation. The branch consists of five shops that provide machining, sheet metal, tubing, welding, and composite fabrication for aerospace and ground requirements. The engineering technicians in the branch are highly skilled fabricators and experienced master craftsmen. Pro-Engineering software is the primary CNC programming system used in the branch to produce complex or sophisticated parts. A production controller on staff will coordinate the outsourcing to offsite manufacturing facilities if the requirements exceed the capacity or competency of the branch.

7.4. Dryden Aeronautical Test Range

Dryden Aeronautical Test Range (DATR) supplies a comprehensive set of resources for the control and monitoring of flight activities, real-time acquisition and reduction of research data, and effective communication of information to flight and ground crews. Precision radar provides tracking and space positioning information on research vehicles and other targets, including satellites. Fixed and mobile telemetry antennas receive real-time data and video signals from the research vehicle and relay this data to telemetry processing areas. The processed data is displayed at the engineering stations in the mission control center and archived in a post-flight storage area. Audio communication networks support research operations in the DATR, covering a broad frequency spectrum for transmitting and receiving voice communications and flight termination signals for unmanned aerial vehicles. Video monitoring provides real-time and recorded data for the control and safety of flight test missions.

7.5. Subscale Flight Research Lab

The Subscale Flight Research Lab performs rapid prototyping, development, and testing of one-of-a kind subscale research and training aircraft that range from micro scale up to 330 lbs. The aircraft and associated support equipment may be manufactured entirely within the lab or may be either unmodified or highly modified commercial off-the-shelf (COTS) equipment or a combination of the two. Unique aerodynamic configurations ranging from low-speed testing of advanced hypersonic shapes to simple, proof-of-concept small Unmanned Aircraft Systems (sUAS) such as hand-launched gliders are often the focus. Operational concepts have varied from controlling the vehicles using conventional Radio Controlled (R/C) systems flown from the ground with visual feedback to conducting missions from within a ground control station using a traditional stick and rudder ground based cockpit with the control signals being telemetered up to, and down from, the research vehicle. The majority of the support tasks for Subscale Flight Research is comprised of design, fabrication, assembly, maintenance and R/C piloting of sUAS assets.

8. Discussion and Observations

NASA AFRC has honed this process over the course of 71 years of conducting flight test on a wide range of vehicle and experiments. There are several keys to the success of this process. The establishment of the Center Chief Engineer as the sole authority keeps the process focused while tailoring the level of review appropriately for the size and scope of the project. The nature of being a small Center with one primary mission focus (flight test) also helps maintain the focus. The use of independent co-workers in a process where the project and the review team share the mutual goals of safe flight and mission success is another key consideration.

9. Appendices

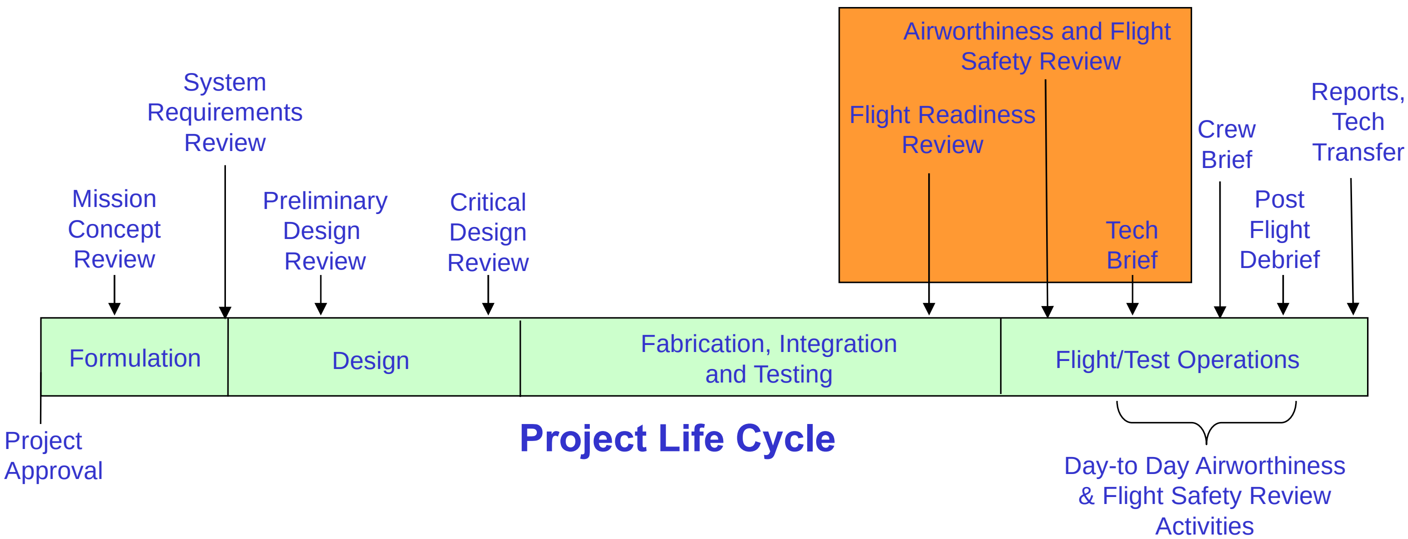
9.1. AFG-7900.3-001 “Airworthiness and Flight Safety Review, Independent Review, Technical Brief and Mini-Tech Brief”

9.2. AFOP-7900.3-023 “Airworthiness and Flight Safety Review Process”

9.3. AFOP-7900.3-022 “Tech Brief and Mini-Tech Brief”

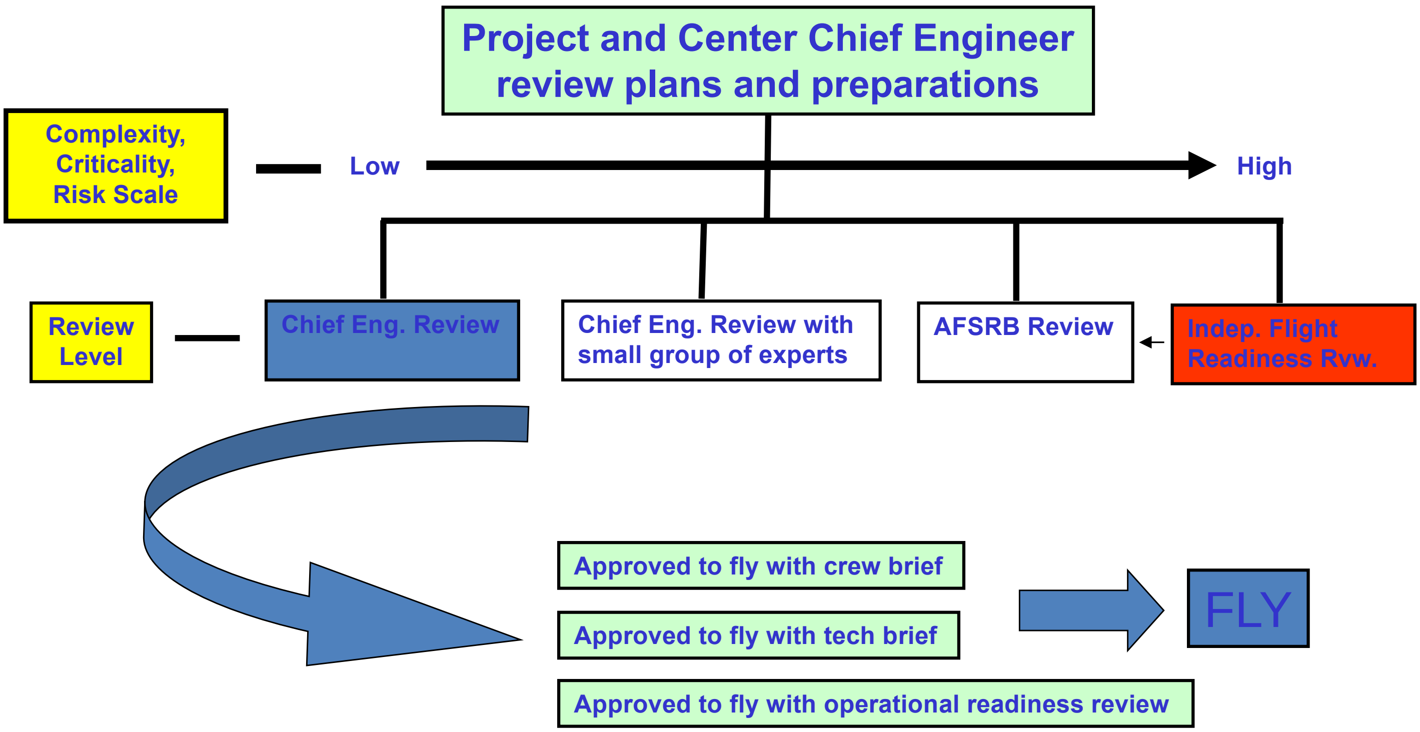
Appendix – 9.4 Systems Engineering and Airworthiness and Flight Safety Review Graphic

Project Life Cycle
Engineering and Airworthiness and Flight Safety Reviews



Appendix – 9.5. Level of Review Graphic

LEVELS OF AIRWORTHINESS AND FLIGHT SAFETY REVIEW



Appendix – 9.6. Hazard Action Matrix (HAM) *Residual Risk*

Human Safety

	Probability				
Severity	**A: Frequent**	**B: Probable**	**C: Occasional**	**D: Remote**	**E: Improbable**
I: Catastrophic					
II: Critical					
III: Moderate					
IV: Negligible					

	Requires Center Director approval and may require approval by a higher authority. These hazards are defined as **"Accepted Risks."**
	Risk acceptance requires Center Director approval. These hazards are defined as **"Accepted Risks".**
	Risk acceptance requires Project Manager approval.

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Loss of Asset/Mission

	Probability				
Severity	**A: Frequent**	**B: Probable**	**C: Occasional**	**D: Remote**	**E: Improbable**
I: Catastrophic					
II: Critical					
III: Moderate					
IV: Negligible					

	Requires Center Director approval and may require approval by a higher authority. These hazards are defined as **"Accepted Risks".**
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