Flight Test Operational Guidance:

A reference provided by the Flight Test Safety Committee (Feb 2017)

Background: Following the fatal mishap involving a Gulfstream GVI (G650) flight test aircraft in Roswell, NM on 2 April 2011, the NTSB in its subsequent investigation recommended that the Flight Test Safety Committee publish and promote flight test operating guidance for manufacturers.

NTSB Safety Recommendation A-12-059: In collaboration with the Federal Aviation Administration, develop and issue flight test operating guidance for manufacturers that addresses the deficiencies documented in this report[1] regarding flight test operating policies and procedures and their implementation, and encourage manufacturers to conduct flight test operations in accordance with the guidance.

The NTSB in its report, noted that "The company's key engineering and oversight errors that led to the accident might have been prevented if the company had (1) better designed the organizational processes used during G650 developmental flight testing, such as those used for workload distribution and sequence of work, (2) codified those processes in a flight test standard operations manual, and (3) trained its personnel on the manual to ensure compliance with the manual's policies and procedures." Further, the NTSB noted that existing SOPs were ineffective in "...establishing control gates for key decision points, implementing processes for validating engineering methods, and clearly defining roles and responsibilities for on-site test team members."

In response to A-12-059, the Flight Test Safety Committee provides the following best-practice recommendations and guidance regarding test team structure, operating procedures, and test execution so that manufacturers and their flight test organizations may use it to develop their SOP and pursue the highest levels of safety.

I. **Test organizations**. Generally speaking, test organizations shoulder the abundance of operational risk for aircraft manufacturers as they perform elevated risk testing, maturing aircraft and systems from cradle-to-grave. Compounding the challenges of day-to-day safe test accomplishment are an abundance of significant schedule pressure and other external factors such as marketing requests, vendor quality issues and production influences to name a few. The effective management of technical risk, program schedule, and test execution help to minimize (or eliminate) latent threats, errors, or omissions that can have catastrophic consequences. Successful management of a flight test organization is about leadership. It is important to have strong leaders with broad test experience, deep technical knowledge of systems-under-test, and formal training in test methods, from detailed planning to sustained operations. Well-documented and mature policies, processes and procedures are vitally important to provide unambiguous

[1] *Crash During Experimental test Flight, Gulfstream Aerospace Corporation GVI (G650, N652GD, Roswell, New Mexico, April 2, 2011, Aircraft Accident Report NTSB/AAR-12/02 (Washington, DC: NTSB, 2012).*
https://www.ntsb.gov/investigations/accidentreports/reports/aar1202.pdf

direction and guidance, but leadership engagement and expectation sets the positive culture in which test teams can operate with sufficient freedom of action and uncompromising discipline. Additionally, flight test representation within the program leadership model can offer tremendous benefits in terms of communication and coordination. Test and Evaluation (T&E) should be part of the overall integrated product/program team from inception, and continue beyond certification for follow-on development and system upgrades. To ensure continuity and continual emphasis of unique flight test challenges, the test organization structure should be periodically reviewed from a holistic program perspective. This will provide sufficient transparency to organizational manning challenges and process drift that can naturally occur as the program progresses.

Recommendation: Conduct an extensive analysis of the test organization using test community experts to design and implement a competent and experienced leadership architecture with knowledgeable technical managers to effectively oversee the test vehicle configuration, maintenance, instrumentation, test planning, team composition, flight scheduling, results reporting, and data analysis; with an eye toward equitable work distribution and a laser focus on risk management. As part of the program organizational structure process, assign veteran tester(s) to participate in the earliest stages of program development. Early involvement in the program allows crucial input on technical maturity concerns, adequate resourcing considerations, and development of an executable integrated master schedule. Test pilots and flight test engineers can add to both the realism of the intended program strategy as well as suggest means to capitalize on efficiencies. Moreover, they can stimulate early identification of test-unique risk scenarios and therefore, should always be included in broader program discussions. Program Management Reviews (PMR) may be an ideal venue to conduct the organizational/process reviews to highlight manning, test vehicle/system, and facility challenges/issues as well as means to spotlight milestone accomplishments. Detailed Test Plan Reviews can also reveal needed resources for safe, efficient and effective testing. Regardless of company/organizational size, appointment of an independent aviation safety officer that reports to upper management can provide unbiased input/oversight and should have the authority to stop testing if safety concerns arise.

II. **Test Team Preparation**. Early test program staffing is a key enabler to commencing the test program with the highest levels of preparation and readiness. Roles and responsibilities should be well-defined, publicly documented (published/announced) and clearly understood. Recruitment and assignment of seasoned flight test personnel should be underpinned with ample training and exposure to the flight test organization's Standard Operating Procedures (SOP) and processes that are integral to a robust Safety Management System (see Section VII). Test training and an effective continuous professional development program are key ingredients to safe and efficient flight test operations.

Recommendation: Conduct a thorough review of flight test processes and functional responsibilities to articulate the work flow in a succinct organizational flight test operating guide or standards manual; preferably well-prior to the commencement of flight test on new programs. Provide indoctrination and continual emphasis on the organization's operating manual to ensure awareness and compliance. An assigned focal point for standardization and training can ensure foundational and continual education/training is not being overlooked or ignored, especially during

the frenetic pace of flight test programs. Provide empowerment to personnel within the flight test organization in accordance with the operational standards manual and expect/reinforce accountability with flight test leadership. Ensure that both periodic and ad hoc reviews, revisions and improvements are incorporated into procedural and process guidance documents.

III. **Test Planning and Risk Management**. Simply put, flight test organizations extract a significant amount of test risk potential through extensive and detailed planning and preparation. Risk management must undoubtedly be the forte of flight test organizations! Professional flight testers should pride themselves on hazard identification and methods to mitigate risk, over and above the sequencing of test events in a logical incremental approach. Rightly, this planning effort should be well-defined and thorough, leveraging industry best-practices and regulatory requirements, feeding critical downstream reviews such as peer test readiness reviews and executive safety review boards as defined in the flight test SOP. The final decision to proceed with elevated risk testing should reside at an executive-level, "grey beard" board to ensure organizational acceptance of the mitigated risk (aka "residual risk") as well as confidence that the breadth of risk mitigation is adequate to present an acceptable level of risk. Leaders at every level should foster an environment that encourages and requires critical thinking, constructive skepticism and constant emphasis on improvement as part of this process.

Recommendation: Test teams should have a documented test planning document that articulates the test plan approval process, including the technical and safety reviews that ultimately lead to acceptance of the residual risk on behalf of their respective corporate entities. Test plans should be authored by a cognizant flight test engineer and a project test pilot. A risk management plan should also be documented. FAA Order 4040.26[2] provides an excellent resource to establish or refine flight test risk management as part of organizational test planning guidance and moreover, can facilitate an agreed-upon risk management strategy with program certification regulators. Formal education and training in test planning and risk management is a key enabler to this process (see Section VIII Training and Standards regarding SMS Component 4: Promotion).

Researching lessons learned and reviewing similar test hazard analysis should be a non-negotiable element of the test planning phase. The Flight Test Safety Committee has created a repository for best practice information[3] and the NASA-sponsored, Flight Test Safety Database[4] also contains flight test reference material in the form of a Test Hazard Analysis (THA) search tool. Robust hazard identification and risk management should be conducted by a multi-disciplinary team for all testing events, and test teams should be cautious with minimalizing this process for off-the-shelf plans, ground tests, or perceived "low risk" flight events. Moreover, teams should aggressively pursue new, safer methods to execute test, collect data, and demonstrate

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[2] *FAA Order 4040.26B dated 01/31/2012 is available at: https://www.faa.gov/documentLibrary/media/Order/4040.26B.pdf*

[3] *The Flight Test Safety Committee is comprised of members from the Society of Experimental Test Pilots (SETP), the Society of Flight Test Engineers (SFTE) and the American Institute for Aeronautics and Astronautics (AIAA). Their charter is intended to promote flight safety, reduce the risk of a mishap, promote risk reduction management and continually improve the profession's communication and coordination. Best practice information can be found at: http://www.flighttestsafety.org/best-practices*

[4] *The Flight Test Safety Database was borne from a flight test community need for flight test maneuver descriptions, test hazards, and risk mitigation techniques. The web site also includes a Test Hazard Analysis (THA) search tool. Flight Test Safety Database can be found at: https://ftsdb.grc.nasa.gov/*

compliance with regulations at every opportunity. Additional lessons learned can be found in technical papers and presentations resident in the archives/databases of the Society of Experimental Test Pilots (SETP)[5] and Society of Flight Test Engineers (SFTE)[6].

IV. **Test Preparation**. Individual roles and responsibilities within the test team need to be defined. For many test events, a mix of flight test engineers and flight science technical matter experts may be employed. Defining critical parameter monitoring duties and time-critical communication flow – within and between the test vehicle, safety/photo chase, and the telemetry team – is paramount. Test teams should exploit all available resources to extract risk from the testing prior to flying. Laboratories are an excellent tool to mature systems and discover potential issues with procedures/techniques, as well as constraints due to operating limitations. Simulators afford an environment to conduct dress rehearsals on normal, abnormal and emergency procedures, as well as to refine test techniques. A cautionary note: it is important to document and communicate observations, results and lessons learned in lab and simulation efforts with aircraft test teams. Even seemingly trivial anomalies in these environments can reveal critical flight and procedural information. Appropriate data gathering means (e.g. instrumentation, photo, audio, transcribed notes) also need to be incorporated into the overall test planning process. Frequently, parameters deemed unnecessary for a planned test have ultimately been found necessary for troubleshooting anomalies, or even preventing mishaps.

Offsite test operations require special planning considerations and coordination. Airport infrastructure, airspace and air traffic control might offer an advantageous environment for specific testing events, however, the site evaluation should include the emergency response resources, location(s) and readiness posture of the provider(s). The Flight Test Safety Committee (FTSC) has prepared and published guidance and a checklist for Aircraft Rescue and Fire Fighting (ARFF). This and an aircraft safety equipment ready-reference card are both available on the FTSC web site[7] as tools to ensure sufficient emergency response readiness for both home-base and offsite operations.

Recommendation: Promote the systemic use of laboratories to the maximum extent practicable to perform comprehensive testing protocols on hardware and software, leading to the issuance of a configuration “safe for flight.” Conduct simulator dress rehearsals as a test team using the approved test plan detailed-method-of-test, emergency, and corrective action procedures. These dress rehearsals also validate the defined test team roles and responsibilities and afford an excellent opportunity to exercise Crew Resource Management (CRM) in a controlled environment. Amend the test plan as required, based on discovery and validation of test plan procedures. Simulation and dress rehearsal “prerequisites” should be included in the test plan and test hazard analysis to lower the overall risk. Simulation and dress rehearsal results should be documented, communicated and reviewed by test teams.

[5] *http://www.setp.org/*
[6] *https://www.sfte.org/*
[7] *http://www.flighttestsafety.org/best-practices*

V. **Test Conduct**.

A. **Test plan compliance and real-time cessation-of-test considerations**

"Plan the flight, fly the plan" is a phrase coined by test pilot schools to instill a sense of discipline and restraint into the conduct of test. Test teams must be trusted to stay on script and not improvise. Moreover, conservative decision-making must be pervasive, and if results are not matching expectations/predictions, then a cease-test declaration is appropriate. Individual team members must feel empowered to communicate/transmit this "cease test" without retribution. Phraseology and timeliness are critical. Test teams should clearly define what the call will be and who can issue the command. For example, "terminate" could mean activation of a flight termination package where "abort" stops the test point in progress. The same individual team members must also embrace an absolute obligation to issue an "abort" call if they feel safety margins are in question. Flight test leadership sets this tone within the culture.[8]

Recommendation: Include, as part of the flight test Safety Management System Component 1 (Policy), a discussion about the uniqueness of flight test (from an operational risk perspective), the imperative for testing with precision (to the plan), as well as transparent, non-attributional communication/reporting.

B. **Workload and fatigue**

Lesson learned: The NTSB, in its investigation of the Gulfstream GVI accident, highlighted the excessive workload shouldered by the principal project FTE. Workload distribution must be actively monitored to preclude the potential for omissions, errors, and fatigue.

Recommendations: Hold flight test managers accountable for subordinate's volume of work and conduct human factors council meetings[9] to assess workforce readiness. Incorporate, as part of the flight test SOP, crew duty day limitations that apply to the entirety of the flight test organization. Monitor overtime as a metric, and embrace an acute awareness to the potential of accumulated fatigue as the pace and schedule pressure increase at milestone test events or across persistent testing blocks.

VI. **Test Progression**. During the course of test, it is beneficial to accommodate and include periodic reviews to assess test results following reduction and analysis. These interim "control gate" reviews provide an opportunity for technical subject matter experts to assess whether results are matching predictions (i.e. modeling and simulation), and that prerequisite data analysis is complete before progressing to testing that is dependent upon prior results. For multi-test vehicle programs (usually the norm), synchronizing and sequencing the testing can have

[8] *An excellent resource on building a healthy safety environment can be found here: http://www.skybrary.aero/bookshelf/books/233.pdf*

[9] *Human Factors Council (HFC) meetings are well established in military flight organizations to address identified human error causality factors in prior mishaps. In short, a small executive team assesses personnel from a professional characteristic standpoint to implement intervention strategies as necessary. More on this concept can be viewed at: https://www.cnatra.navy.mil/pubs/folder2/5420.13F.pdf*

significant efficiency *and* safety implications. Everything from configuration management to results reporting requires focused attention and exceptional coordination to combat tribal knowledge, inadvertent omissions, and wasted effort. For programs that enjoy robust lab and simulator capabilities, the synchronization and communication must include that additional reach-back to ensure relevant discoveries from these resources are expeditiously shared with flightline testers and vice versa. Some anomalous/undesirable results should be expected in the course of a flight test program. When they occur, it is important the reporting process provides expeditious notification followed by accommodation for the test team to stop and assess. Documenting and communicating the results of investigations, technical meetings and subsequent corrective actions/risk decisions ensures transparency as well as content for future reference and learning.

Recommendation: Treat flight test as a "system of systems" that requires seamless communication and coordination from program office, lab facilities, maintenance, and test team. A program operating guide can be helpful to define the reporting relationships and establish the "drumbeat" for periodic reviews on testing progress. Utilize the same program leadership-level flight test expert to gage where gate reviews are strategically necessary in the overall program schedule as well, prove beneficial as a periodic health check of test progression. As program requirements and schedules continue to evolve and mature, so must the timing and potential addition of new reviews based on results, events and/or changing requirements. At the tactical level, incorporate technical "control gate" reviews (essentially "interim data reviews") as necessary in the test plan to solidify an expectation of the required review and to provide accommodation within the test schedule. These gate reviews are pre-planned and are necessarily different than a "pop-up" reconvene of a safety review board for an unexpected or anomalous test event. The gate review is focused on examining the incremental results of testing (including lab/simulation results) against pre-planned expectations to ascertain deviation from the performance model. A critical event review process, requiring an SRB to reconvene, should also be well-defined as a discrete event.

VII. **Safety Management System (SMS)**. By definition, a Safety Management System is a formal, top-down, organization-wide approach to managing safety risk and assuring the effectiveness of safety risk controls.[10] Generally, flight test organizations already have existing risk management processes and may even have safety policies in place. Remember, risk management should be the forte of test organizations! Organizing policy, risk management, performance assurance, and safety promotion elements into the four component structure of an SMS is more an administrative exercise than the creation of entirely new safety processes. The primary challenge is to ensure company top management is fully supportive of the SMS and embraces the necessity of establishing a safety culture which provides the focus and stimulus for continual safety performance improvement. The culture should encourage and reward reporting, not focus on individual blame. Recognition, promotion and communication of correct risk behaviors are the underpinning of a positive safety culture and are a leadership responsibility.

[10] *See FAA Advisory Circular 120-92B (of 1/8/15), Safety management Systems for Aviation Service Providers (https://www.faa.gov/regulations_policies/advisory_circulars/index.cfm/go/document.information/documentID/1026670), and International Civil Aviation Organization (ICAO) Doc 9859, Safety Management Manual 3rd edition – 2013 (http://www.icao.int/safety/SafetyManagement/Documents/Doc.9859.3rd%20Edition.alltext.en.pdf)*

Commercially available SMS programs are typically designed for established flight departments, and their corresponding auditing protocols are tailored for those types of operations. For business aviation, the International Business Aviation Council (IBAC) created an International Standard for Business Aircraft Operations (IS-BAO)[11]. This voluntary standard has become popular with Part 91 and 135 operators as a means to stimulate safety improvement, demonstrate a visible means of SMS commitment, and to satisfy international travel regulatory requirements. The Flight Test Safety Committee has created flight test-specific auditing protocols adapted from the IS-BAO and the Safety Management International Collaborative Group (SMICG) SMS Evaluation Tool[12]. These continue to be refined as flight test organizations adapt and use the tool to guide SMS development for flight test, and to assess their SMS maturity (a key element in SMS Component 3: Safety Assurance).

The FAA Aircraft Certification Service (AIR) initiated a pilot project in 2014 to feed proposed rulemaking (expected 2018) for Part 21 design and production approval holders, to have an SMS which incorporates the ICAO Annex 19 elements. The Aerospace Industries Association (AIA) and General Aviation Manufacturers Association (GAMA) have jointly developed an industry standard[13] to assist design and manufacturing organizations to voluntarily implement an SMS. The FAA recognized this standard as satisfying the Annex 19, providing a means to assess an applicant's voluntary SMS program as conforming to the 14 CFR Part 5 intent[14]. It is clear; having an SMS is necessary and in the not-to-distant future, an SMS that addresses flight test specific considerations will be required. Consideration should be given to not just having a stand-alone organizational ("stovepipe") SMS, rather, a well-integrated and harmonized system that infuses appropriate safety focus across the product life cycle.

Recommendation: Establish and continually mature a flight test SMS. Secure absolute and uncompromising support from company leadership to embrace safety as part of company strategic values. Consider both internal and external auditing of SMS that is preceded by culture surveying. Pick a flight-test-tailored standard and stay engaged with community safety information sharing and best-practice improvements that are aimed at boosting safety performance within the flight test organization. Cultivate a robust non-attributional reporting culture that feeds a responsive and thorough investigative process that seeks root cause and accommodates human factors[15]. Flight test and company leadership must "walk the talk" with regard to following the established safety processes. Overreacting, interrogating individuals or suppressing organizational/supervisory factors of a reporting/investigative process will undermine trust and erode confidence in the safety system. Any finding of culpability should be based on factual information and debated thoroughly at a cross-disciplinary event review team to ensure consistency and sufficient representation for involved individual(s). Sharing of lessons learned

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[11] http://www.skybrary.aero/bookshelf/books/1774.pdf

[12] http://www.flighttestsafety.org/images/Flight_Test_SMS_Audit_Protocols_FTSC_Submission.pdf

[13] *AIA/NAS9927: Safety Management System Practices for Design and Production. Standard can be found here:* http://standards.globalspec.com/std/10015556/aia-nas-nas9927

[14] https://www.faa.gov/about/initiatives/sms/specifics_by_aviation_industry_type/design_and_manufacturing_organizations/

[15] *The Human Factors Analysis and Classification System (HFACS) is one of many investigative taxonomies that can provide further identification of mishap human factor causality.*
See: https://www.nifc.gov/fireInfo/fireInfo_documents/humanfactors_classAnly.pdf

should be encouraged through the establishment and sustainment of a non-attributional safety culture.

VIII. **Training and Standards**. As part of SMS Component 4 (Promotion), safety communication and training is expected to be seamless across the test organization. A horizontally integrated SMS can enable transparency and expeditious flow of safety critical information. Large, multi-vehicle/multi-model test programs can add tremendous complexity to the test organization which can challenge event notification, root cause investigation and corrective action implementation reporting/updating. Leadership in this area is critical.

Flight test workforce education and training should be viewed as a continuum – apprentice to master. Certainly, onboarding a qualified and experienced test force should be a primary objective, but ensuring the team is well-versed on company-specific policies, procedures and methods will avoid confusion, inefficiencies and emotionally-charged friction. A broad management view, promotion and coordination of employee professional development will result in higher workforce performance and morale. Flight test is a unique technical profession with ample opportunity for foundational and continual educational opportunities. Certificate and Masters Degree programs in flight test are available, as well as a menu of short-course and focused training options.[16]

Recommendation: Consider application-based, electronic means to disseminate safety information, particularly for large, geographically dispersed programs. Digital signature capabilities allow a rapid means to ensure receipt and acknowledgement across a test force. Establish pre-populated addressee lists to ensure all appropriate contacts are kept informed and actively prevent ad-hoc emailing or sequestering of time-critical test safety information.

As part of new hire indoctrination, provide necessary company-specific/organizational SOP training and SMS familiarization. Ensure all training is documented and tracked. For new acquisitions or transitions, consider enrollment in a flight test certificate or advanced degree program. Operationally-based training such as survival training, egress training (project specific) and aviation physiology training (hypoxia awareness) should be a prerequisite to participation in flight testing. Pilots need to be current and proficient in test techniques and if needed, should be allowed to train and practice in similar aircraft prior to flight testing in new models. These types of training should have a periodicity and trigger “clearance to fly” in the scheduling process. It is a management responsibility to provide sufficient funding and employee attendance opportunity (expectation) for both initial and recurrent training. Moreover, it’s highly advantageous for management to encourage attendance and participation in broader flight test community education opportunities (e.g. short courses in icing tests, pilot induced oscillation, upset recovery, etc. or even long-term courses at accredited institutions or test pilot schools), symposia and

[16] *http://www.fit.edu/programs/8233/ms-flight-test-engineering#.WCyVmNgzVD8*
http://www.navair.navy.mil/nawcad/index.cfm?fuseaction=home.content_detail&key=DCAC2041-1A83-4E1D-AF59-E88D8225EB6C

workshops where lessons learned and best practices are exchanged freely (e.g. the Flight Test Safety Workshop hosted by the Flight Test Safety Committee[17]).

Summary: Flight test is a highly challenging and rewarding profession. Tragically, we re-learn lessons that needlessly cost lives, destroy valuable test assets, and jeopardize programs. The production/progress versus safety balance can easily be tipped in a dangerous direction when safety is compromised by inducing excessive schedule pressure, ignoring or suppressing telltale warnings, and/or generally not engaging in proven safety processes or practices. The flight test community prides itself on navigating a spectrum of elevated risk operations to ultimately certify high-performing and safe air vehicles and systems. Participating in flight test community membership organizations such as the Society of Flight Test Engineers (SFTE), Society of Experimental Test Pilots (SETP) and Royal Aeronautical Society (RAeS)[18] affords test professionals an excellent opportunity to exchange best-practice information, and transport critical flight test technical and safety information back to their respective test teams. Consider this a strong recommendation to enhance your organizational SMS safety promotion!

Cultivating and promoting a culture that fosters integrity, esprit de corps, and continual improvement is a persistent leadership challenge. Successful flight test organizations thrive on teamwork and pride in professionalism. Implementing the “mechanical” components of SMS and other flight test processes without focusing on a positive safety culture will likely not yield the results desired, and may unnecessarily expose the flight test organization and parent company to latent threats. The Flight Test Safety Committee welcomes feedback on improving flight test practices and encourages broadly sharing best practices throughout the flight test community.

[17] *http://www.flighttestsafety.org/workshops*

[18] *https://www.aerosociety.com/*