AIR FORCE STRUCTURES

Structures Bulletin

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Subject: Structural Overloads – Mishap Assessment and Disposition Process

References:

1. Department of Defense Standard Practice, MIL-STD-1530C, "Aircraft Structural Integrity Program", 1 November 2005
2. JSSG-2006, "Joint Service Specification Guide Aircraft Structures", 30 October 1998
3. TO 1-1B-50, "Joint Service Technical Manual - Aircraft Weight and Balance", dated 1 Aug 2015

Background:

The goal of the Aircraft Structural Integrity Program (ASIP) as described in Reference 1 is to ensure the desired level of structural safety, performance, durability, and supportability with the least possible economic burden throughout the aircraft's design service life. Use of the five primary ASIP tasks is predicated on the aircraft usage remaining within the established operational limitations. Disposition of aircraft structure for mishap events resulting in structural overloads may involve revisiting elements of Tasks II-IV of ASIP using the guidance documented in Reference 2. This Structures Bulletin describes the steps to disposition an aircraft structure that has been subjected to loads in excess of the design limit load. The process described and shown in Figure 1 is to evaluate and assess the integrity of the mishap aircraft (MA) structure by determining the loads for the mishap event, identifying components with compromised structural integrity, and validating repairs and/or modifications to restore the structural integrity of the MA. The cost & schedule associated with the process to restore structural integrity should be compared to the alternatives of imposing flight limitations, revising the service life limit, adding maintenance requirements, replacing structural components, implementing repairs/modifications, and retiring the aircraft.

Discussion:
The disposition process, outlined in Figure 1 identifies the key tasks for ensuring that the external loads for the mishap event are quantified, the impact to the structure's strength, rigidity, durability and damage tolerance are assessed and validated, and required modifications or additional maintenance actions are validated.

1) Post mishap event inspections:
   Technical Orders (TOs) should provide details on the initial structural inspections of the MA for an overload event. However, the full extent of the structural inspection requirements will likely not be evident until the magnitude of the overload condition is determined and the strength and the durability and damage tolerance (DaDT) analyses of the MA structure are conducted.

2) Mishap event external loads:
   Analytical determination of external loads for the mishap event should be based on data collected during the mishap event. For example, measured flight parameters, data from onboard instrumentation, and mishap videos can be used to derive external loads. If the external loads are beyond validated analyses predictive capabilities, the aircraft instrumentation is not calibrated to the load exceedance levels, or there is not sufficient data from the overload event, the mishap external loads will have to be estimated. Confidence in the mishap external loads estimations will depend on the extent of loads model and instrumentation data extrapolation beyond their validated/calibrated levels and on the correlation of predicted damage to inspection results. Prior to any disposition of the MA structure and based on the mishap event external loads, a preliminary assessment of the process outlined in Figure 1 should be conducted to determine the economic and programmatic feasibility of restoring structural integrity to the MA.

3) Static strength:

   a. If the airframe strength models are not validated to the mishap load conditions and load levels, a strength model validation effort must be conducted. Static tests of MA representative structure test article(s) with the mishap event critical load case(s) shall be conducted to show that deflections, local failures, and permanent deformation from test articles match those predicted using the strength models. This may require updates to the strength models to include material and geometric nonlinearities, new failure models, etc. and associated validation testing. Depending on the magnitude of the overload, the extent of the structure impacted by the mishap event and the complexity of the structure, full scale test articles may be required to fully validate the strength models.

   b. Using the critical loading cases(s) for the mishap event, use the validated strength models to predict locations, types, and extents of damage and permanent deformations for the MA. The analyses should consider the possibility that permanent deformations change the local stress distributions, resulting in:
      i. Fastener hole elongation and loose fastener consequences
      ii. Yielding or buckling of parts that result in load path changes
      iii. Delaminations and disbonds

iv. Detrimental deformations

c. Initial inspection requirements triggered by the mishap event typically will not be sufficient to identify all damage and permanent deformation at all of the critical locations identified by the strength analyses. Therefore, a detailed nondestructive inspection (NDI) for all possible damage locations identified using the strength models must be conducted. The NDI should be tailored to details of the structure geometry, material type, and the predicted extent and type of damages. Although deformation due to material yielding can be quantified by measuring permanent deformations, pre-mishap structural measurements are required for comparison making quantification of material yielding difficult. For non-inspectable areas with potential hidden damage, particularly for structure that is safety of flight, conservative assumptions for the presence of damage may be warranted.

d. A comparison of validated strength models predictions for locations, types, and extents of damage to the damage found during the detailed inspections of the MA provides a measure of the accuracy of the external loads used for the analyses. If there are significant differences between the predicted damage and the actual damage found in the MA, additional work will be required. If the external loads were estimated, additional tests and/or analyses must be conducted to improve the loads estimates and steps 3b and 3c must be repeated. If the external loads were derived from validated loads models, then the strength models predictions and/or the inspections are suspect and must be re-evaluated/updated until the predicted damage matches the actual MA damage. Since damage such as material yielding is not readily detectable, there will remain some uncertainty that estimated external loads match the actual loads of the mishap event simply by comparing observed damage and predicted damage.

e. An assessment of the MA structure to meet the limit load and ultimate load strength requirements must be conducted. Using the validated strength models with the mishap external loads, identify the locations and magnitude of structure with negative Margins of Safety (MS) and predict the locations and magnitudes of material yielding and resultant residual stresses. Since composites and bonded joint allowables are temperature and moisture dependent, if the temperature and moisture content of the mishap structure is known at the time of the event, the allowables for those specific temperatures and moisture conditions can be used to determine MS for the critical loading cases*. If the MA structure does not meet the strength requirements (accounting for residual stresses) and restrictions to the flight envelop are not acceptable, the structure must be repaired/modified, replaced, or retired.

f. The design of repairs or modifications to the MA structure to meet strength requirements must account for all residual stresses that remain in the parent

*Inherent in this approach is the assumption that for composites and bonded joints, the materials and components exhibit linear elastic behavior up to failure (ie. no yielding) and that there are nondestructive evaluation methods that can detect damage. The assumption that the composite materials and bonded joints behave linear elastically up to failure must be substantiated by test data.

structure after the structure is repaired or modified. That is, the MS for the repaired/modified structure must be non-negative with the residual stresses accounted for in the MS calculations.

g. For substantive repairs and modifications, the static strength of the modified/repaired structure must be validated by testing MA structurally representative test articles that include representing the material yielding and residual stresses that may have been incurred during the mishap event. The repaired/modified structure must meet the limit load and ultimate load static strength requirements.

4) Durability and Damage Tolerance:
Although the critical external loads substantiation is based on measurable damage and deformation of the MA structure, the fidelity of this substantiation does not necessarily support an accurate determination of the remaining life of the structure. This is due to the inability to confidently predict and nondestructively evaluate material yielding and residual stresses. The potential for compressive overloads to introduce residual tensile stresses may result in increased fatigue stresses, reduced critical flaw sizes, and cancellation of cold working benefits. The potential for tensile overloads to propagate and/or accelerate the growth of damage tolerance flaws may result in multi-site damage.

a. If the DaDT models are not validated for mishap event exceedance load levels, a DaDT model validation effort must be conducted. Durability tests on representative mishap structure test article(s) with the mishap critical load(s) shall be conduct to show observed damage from test articles match those predicted using the DaDT models. This may require updates to the DaDT models to include new crack growth and crack retardation models, modifications to account for residual stresses, etc. and associated validation testing. Composite structures have been shown to be sensitive to high loads and current DaDT models for composites cannot accurately model their effects. If the effects of such high loads have not been characterized in design development tests, durability tests on MA representative composite structure test article(s) with the mishap critical loads shall be conduct to verify the structure meets the service life requirements. Depending on the magnitude of the overloads and the extent of the structure impacted by the mishap event, full scale test articles may be required to fully validate the DaDT model.

b. An assessment of the MA structure to meet the remaining service life requirement must be conducted using validated DaDT models. To assess the remaining service life, the assumed flaw sizes at the time of event shall be the damage tolerance initial or inspectable sizes plus growth in twice the flight hours since last inspection. The assumed past usage severity shall be per the latest developed baseline spectrum (unless usage data shows otherwise). The life assessment shall account for mishap event loads and residual stresses predicted by validated strength models. Additionally, the effects of possible invisible, hidden or non-inspectable damage such as residual stresses due to yielding, elongated holes or loose fasteners, and cracked or bent fasteners shall be considered.

c. Predictions for the remaining service life of the mishap structure shall be validated by tests on MA representative elements, subcomponents, and components test articles as necessary (apply loads spectra to simulate flight prior to mishap, apply mishap load case(s), continue with loads spectra) and compared to baseline structure without the mishap loads. If the MA structure does not meet the remaining life requirements (accounting for residual stresses) and restrictions to the service life are not acceptable, additional inspection requirement can be instituted or the structure must be repaired/modified, replaced, or retired.

d. The design of repairs or modifications to the MA structure to meet the remaining service life requirements must account for all residual stresses that remain in the parent structure after the structure is repaired or modified. Predictions for the remaining service life of the repaired/ modified and parent structure if applicable shall be conducted. If the repairs/modifications are extensive, the remaining life of the repaired/modified structure shall be validated by tests as necessary.

5) Dynamics:

If the MA structure is repaired or modified to meet strength and/or DaDT requirements, changes to the structural stiffness and/or mass may alter its dynamic response. Therefore the effects of repairs or modifications on vibro-acoustic and flutter behavior must be assessed.

a. For repairs or modifications to vibro-acoustic critical structure, analyses of the vibratory response of the structure shall be conducted to verify that the repaired or modified structure can meet the required service life requirements. If the analysis indicates that the vibro-acoustic requirements are not met, additional repairs or modifications to the structure may be required. *If additional repairs or modifications are necessary to meet vibro-acoustic requirements, a reassessment of the strength and DaDT may be warranted.*

b. Flutter analyses must be conducted if repairs or modifications are expected to alter the dynamic response of the aircraft. If the analyses indicates that the flutter or damping response significantly changes, it must be determined if the flutter and damping margins are significantly degraded. If the structure does not meet requirements, either operational limitations can be imposed or additional repairs/ modifications to meet the flutter and damping margins can be added. If the analyses are not validated for the repairs or modifications, rigidity/ground vibration tests and/or flight tests should be conducted as necessary. *If additional repairs or modifications are required to meet flutter and damping requirements, a reassessment of the strength and DaDT may be warranted.*

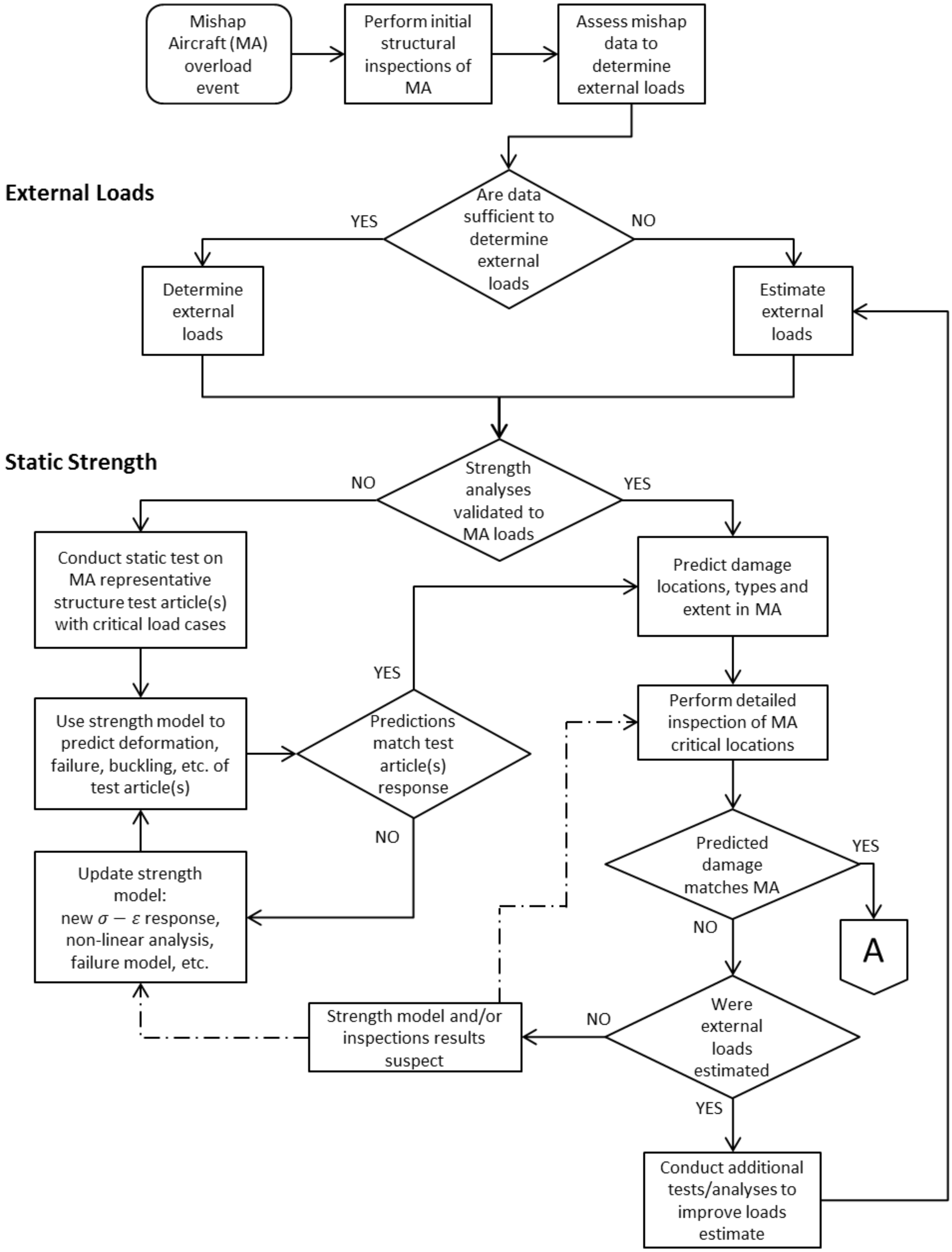
6) Mass Properties/Weight and Balance:

Repairs and modifications to the aircraft may change the weight and/or the center of gravity requiring updating the DD Forms per TO 1-1B-50. If required per TO 1-1B-50, the aircraft should be weighed to verify the weight and center of gravity analyses.

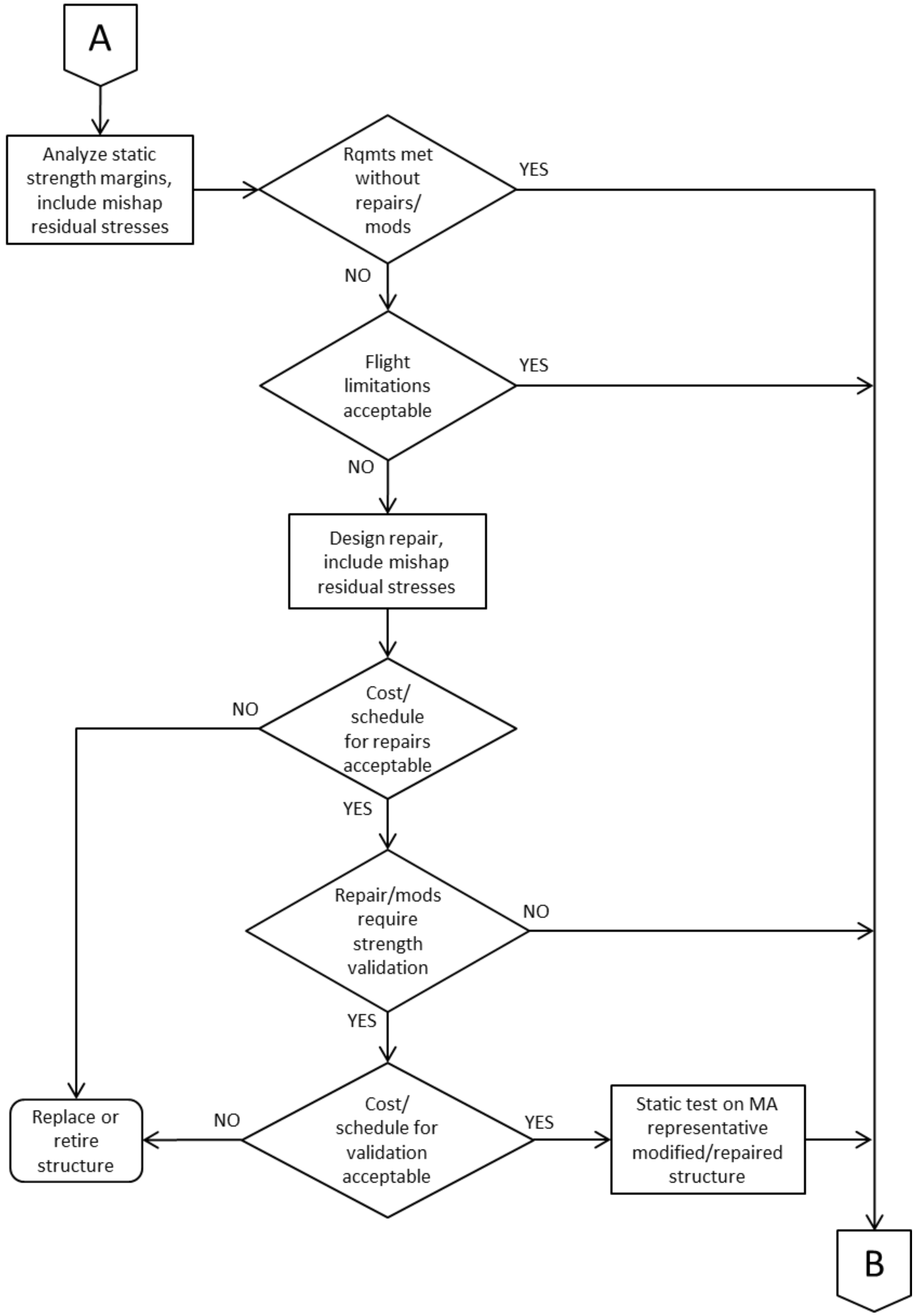
7) Flight Release:
   a. Document all repairs, modifications, and component replacements so as to maintain configuration control. These records shall include a description of each repair, modification, and component replacement and when (e.g., date, flight hours, flight cycles, equivalent flight hours) it was incorporated.
   b. Document new operational restrictions and/or maintenance requirements into all applicable T.O.s, etc. Document results of all analyses and tests and include summary in ASIP Master Plan. Update the Force Structure Maintenance Plan (FSMP) and Individual Aircraft Tracking (IAT) program and reports as necessary.

Recommendations:
An overload event can have severe impact on the integrity of aircraft structures and disposition of the MA airframe may entail significant analyses and testing efforts to insure the structure has or is restored to the required strength, rigidity, and durability and damage tolerance capabilities. The significance of the effort to disposition the structure is highly dependent on the magnitude of the overload and whether or not the loads, strength and DaDT models are validated to the exceedance load levels. A preliminary assessment of the disposition process outlined in Figure 1 to evaluate load exceedance levels, analysis capabilities, and estimation of required testing and analysis should be conducted. The results of the preliminary assessment should provide sufficient data to estimate the cost and time to fully disposition and repair the aircraft and to determine the economic and programmatic feasibility of doing so. This initial assessment should be conducted prior to any repair activities.

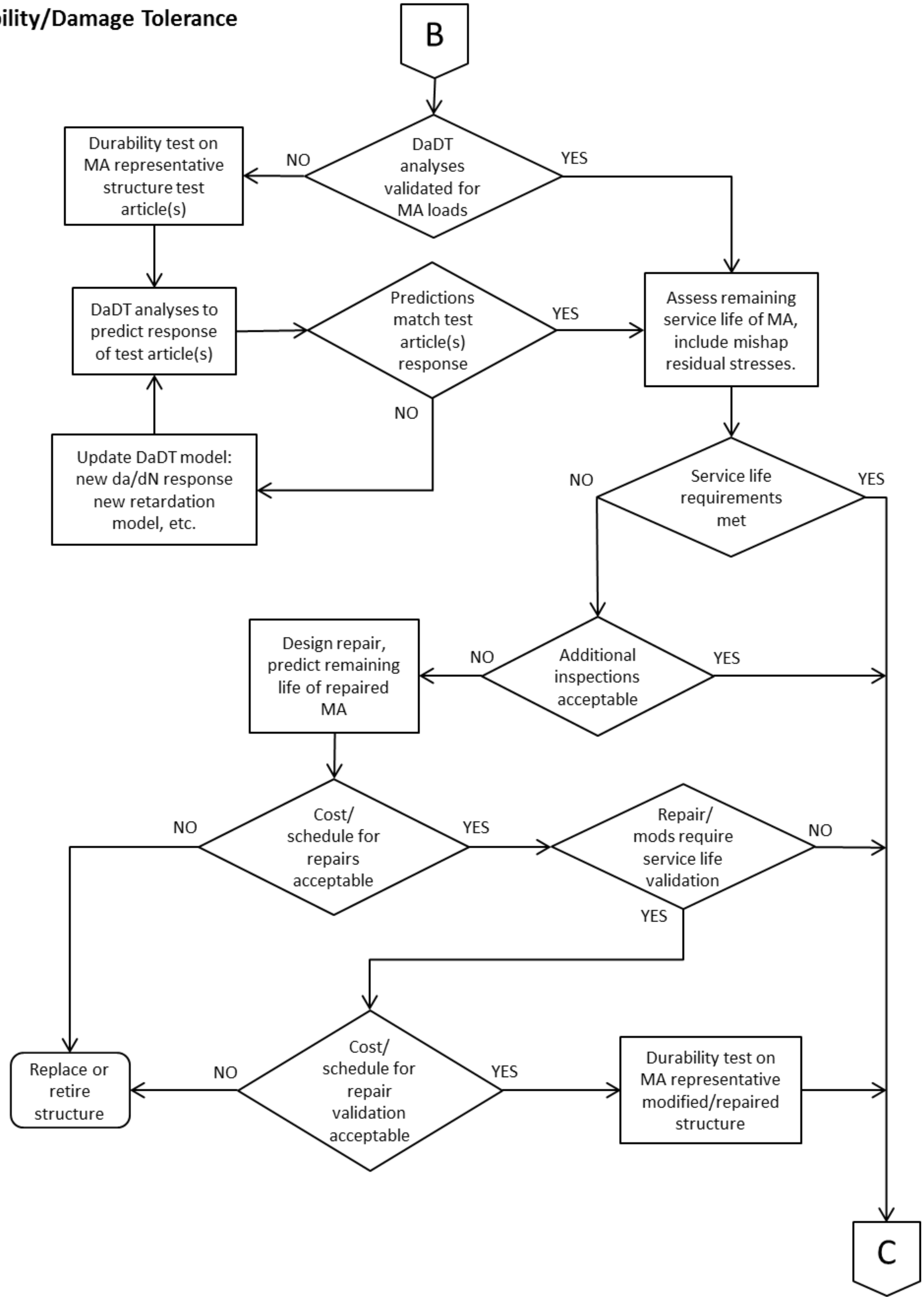
Figure 1. Disposition for a Structural Overload



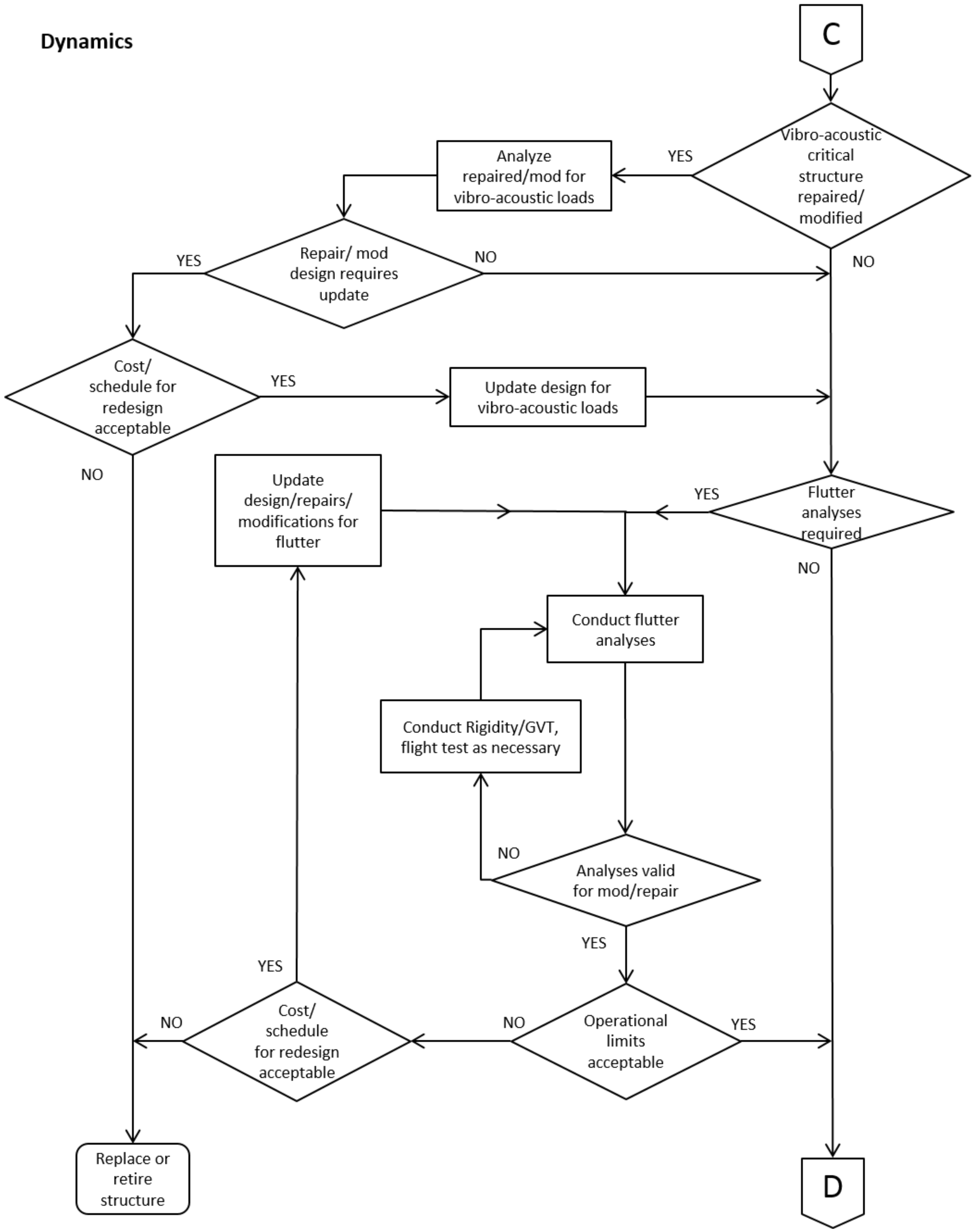
Static Strength (continued)



Durability/Damage Tolerance

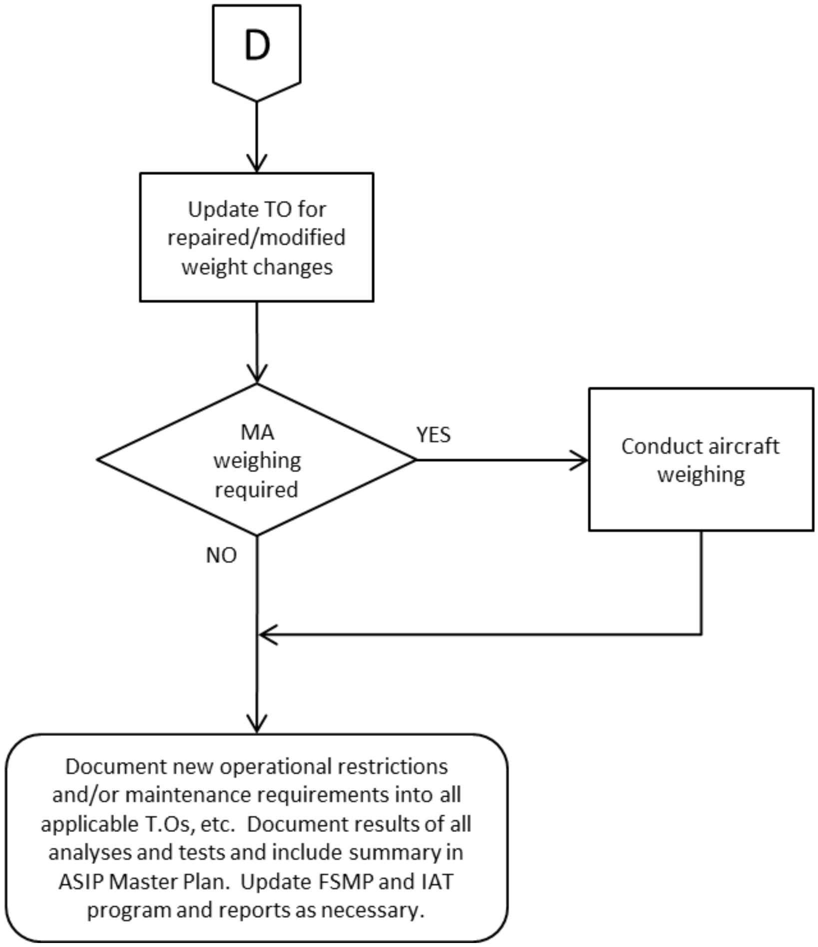


Dynamics


C
Vibro-acoustic critical structure repaired/ modified
YES
Analyze repaired/mod for vibro-acoustic loads
NO
Repair/ mod design requires update
YES
NO
Cost/ schedule for redesign acceptable
YES
Update design for vibro-acoustic loads
NO
Update design/repairs/ modifications for flutter
YES
Flutter analyses required
NO
Conduct flutter analyses
Conduct Rigidity/GVT, flight test as necessary
NO
Analyses valid for mod/repair
YES
YES
Cost/ schedule for redesign acceptable
NO
NO
Operational limits acceptable
YES
Replace or retire structure
D

Mass/Weight Balance

Flight Release



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