ARDEC Computationally Based Engineering (CBE) Capabilities and Their Validation Tools

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Abstract

Prolific use of the phrase "Modeling and Simulation" throughout the DoD has given rise to great confusion in the community. As time has progressed this, often over used, phrase has been afforded different meanings depending on the audience or venue where it is used. It has been suggested [1] to begin using the phrase Computationally Based Engineering (CBE) to differentiate the physics based modeling from other types of models such as force-on-force models, production processing models, etc. An overview and description of the advanced CBE capabilities and tools at The Armament, Research, Development and Engineering Center (ARDEC) are presented. These CBE tools are of limited value without proper validation. Various test devices to validate the CBE models as well as the current processes for integration of CBE models into test rubrics are discussed in order to provide a complete picture of the overall capability that now exists.

[1] Farhat, Charbel, Army High Performance Computing Research Center Annual Meeting, Stanford, CA, 16 October 2013

Outline

- Background
- CBE Tools
- Validation of CBE Tools
- Conclusions

Background

- Modeling and Simulation is Vague
  - Force on force modeling (Wargaming)
  - Production flow modeling
  - Behavioral modeling
  - Physics based modeling
- Computationally Based Engineering (CBE)
  - Finite element/Finite volume/Boundary element
  - All physics based models
- Paper Will Describe CBE Modeling Tools and Methods of Validation
  - Focusing on gun launched structures

Computationally Based Engineering: Benefits

- Benefits of CBE
  - See detailed stresses and displacements from dynamic loads
  - Compare proposed design improvements
  - Evaluate designs that may be unsafe or impractical to test
  - Assess product improvements before changing production
  - Optimize systems for improved reliability or cost
  - Analyze “What if’s” in root cause investigation
  - ‘Watch’ movements in fuzes and MEMs devices that could not otherwise be observed

Computationally Based Engineering: Drawbacks

- Drawbacks
  - All models need to be validated – for munitions we gun-fire
  - Workforce must be continually trained
    - Untrained workforce can obtain a VERY wrong answer
  - Software and hardware recurring costs quite sizable and must be maintained
  - Initial modeling efforts may actually take longer than a test
    - Payback occurs afterwards because of insight gained through the models
  - Material properties must be well characterized
    - Testing is expensive; Material expertise required
  - Loading on components must be understood
    - This can also require expensive tests

CBE Predictive Tools at ARDEC

- **Hardware**
  - 1-LINUX, 564 cores (processors)
  - 1-LINUX, 544 cores (processors)
  - 1-LINUX, 756 cores (processors)
  - Local small clusters

- **Access to DoD HPC facilities**
  - **MSRC**
  - **TACOM-Warren**
  - **AFRL – Hawk/Raptor**

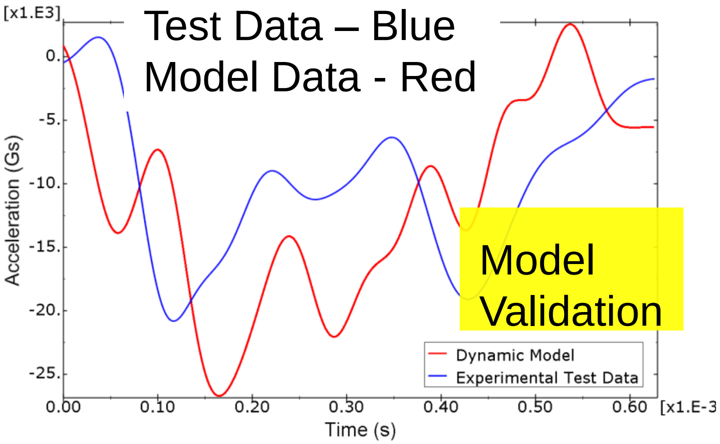
- **Software**
  - Static and Dynamic Structural Analysis
    - **ABAQUS – Commercial code, Beta Test Site**
    - ANSYS – Commercial code
    - Sierra Solid Mechanics – Sandia National Labs
    - ALE3D – Lawrence Livermore code
  - Computational Fluid Dynamics
    - Fluent – Commercial code
    - CFX – Commercial code
    - Star/CD – Commercial code
  - Reliability Software
    - Prediction Probe
    - CALCE tools
  - Critical Defect Size: NASA/FLAGRO – NASA code
  - Fatigue Evaluation: FESafe 4 Fatigue
  - NASA Failure analysis software

CBE of New Design: Surveillance Grenade Development

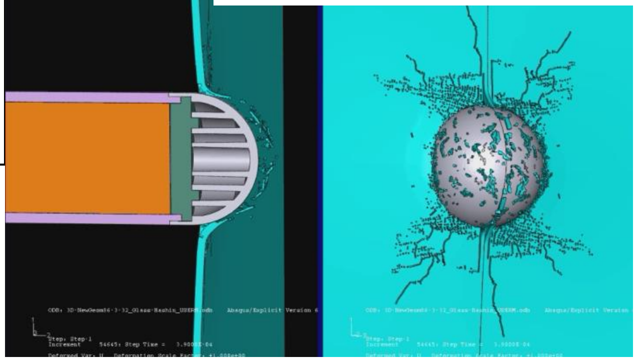
- Issue
  - Non-lethal listening device
  - Surveillance grenade requires electronics to survive impact and relay information to the Warfighter
- Modeling Effort
  - Modeled multiple designs for front end of grenade to absorb impact
  - Each iteration at various impact angles
  - Currently finalizing design for LRIP
- Verification: damage match-up to tests
- Benefits
  - Saved 2-3 years of trial and error testing
  - Saved an estimated $1M to date

Modeling & Simulation helped bring effort to Low Rate Initial Production in 2 years

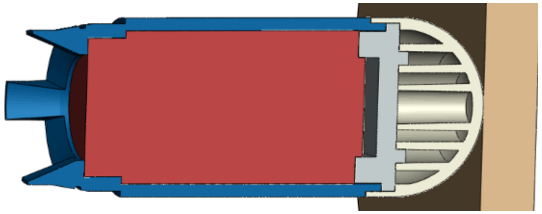
Test Data – Blue
Model Data - Red

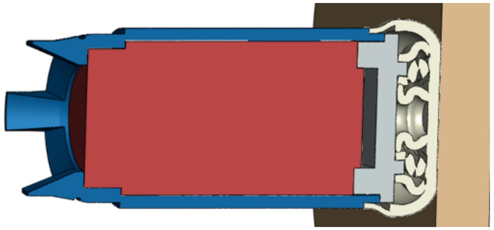


Model Validation



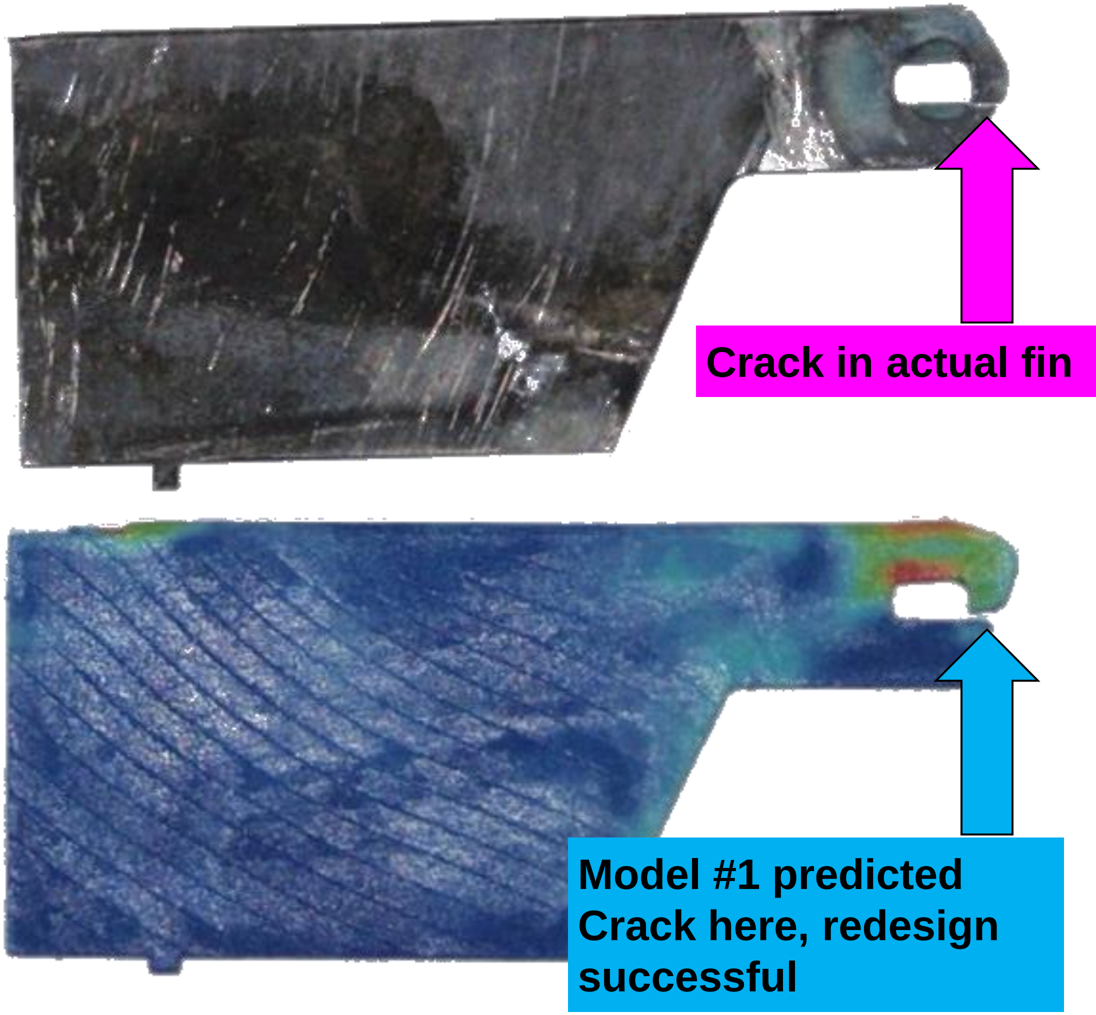
Modeled many “what if designs”





Analysis of Fin Breakage

- Issue
  - ➢Root Cause investigation after fin failure
- Modeling Effort
  - ➢ Dynamic CBE analysis of 105-mm projectile
  - ➢ Modeled fin with Johnson Cook material model (steel)
  - ➢ If we can model failure, we can model/test a fix
- Benefit
  - ➢ Predicted type and region of failure
  - ➢Used findings for redesign
  - ➢Improvements utilized for successful flight tests



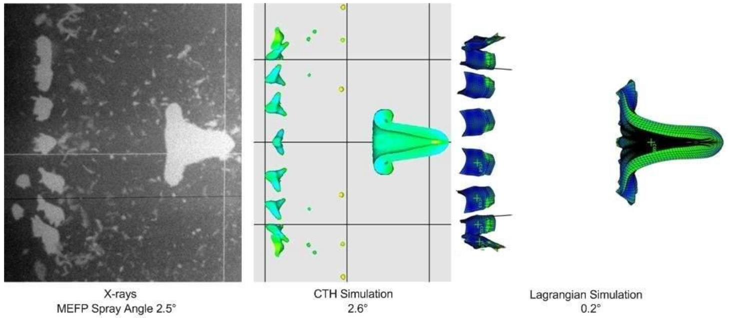
Crack in actual fin

Model #1 predicted Crack here, redesign successful

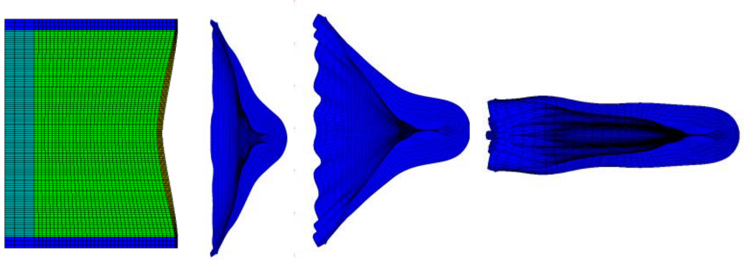
Successful prediction of failure, redesign, and validation flight tests

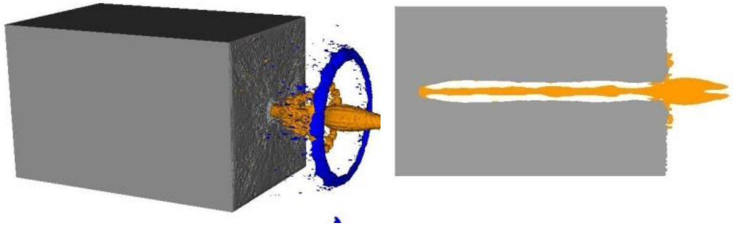
Warheads

- Issue:
  - Penetrator design is complicated and requires several iterations for optimized performance
  - Fabrication of liners is expensive and time consuming
- Modeling Effort:
  - Modeling of designs for jet characterization and formation
  - Early estimation of penetration before build/test of hardware
- Benefits: Significant cost savings and better designs
  - Many designs are iterated without the need to build expensive hardware
  - Design time greatly decreased
    - Design – Model – Results = 1 week
    - Design – Fabricate – Load – Test = 3 months minimum

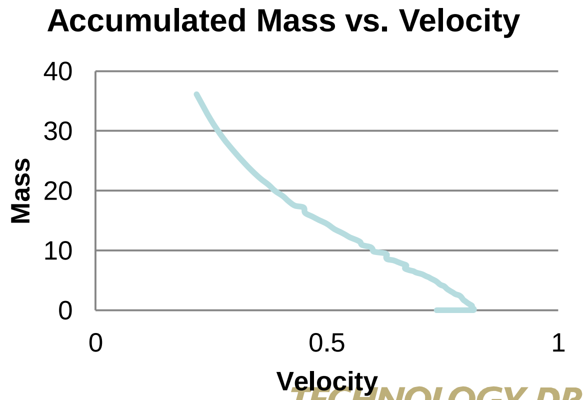


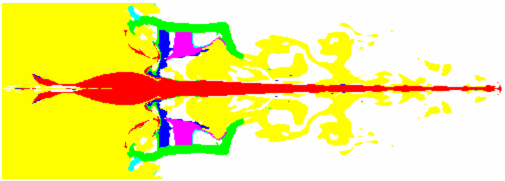
Models of MEFP designs closely match test x-rays





3D Fluted spinning shaped charge penetration simulation

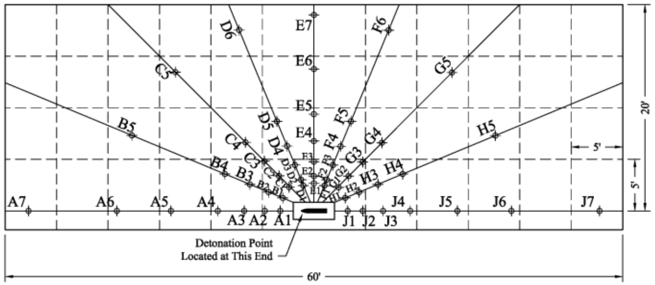


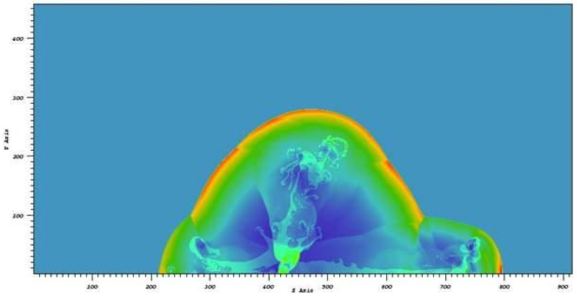


2D simulation of spit back initiated shaped charge

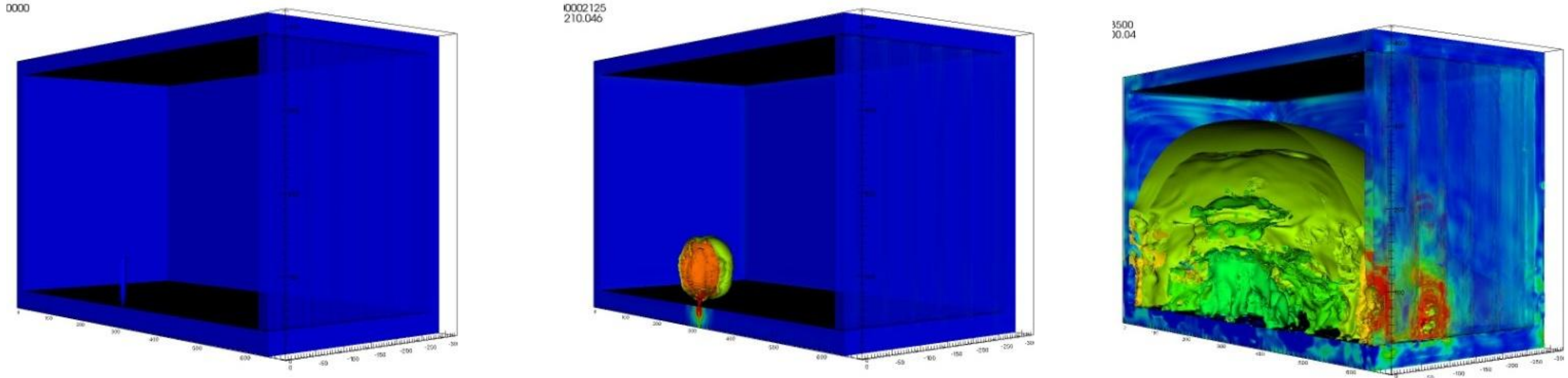
Blast Wave Propagation

- Issue:
  - Predicting blast pressure profiles of various explosives is becoming increasingly important
  - Important to determine the target effects and structural response from explosive shock waves
- Modeling Effort:
  - Modeling open air blast can be used to calibrate high explosive equations of state by comparing to tests conducted in open air environments
  - These equations of state can then be used to conduct modeling and simulation of explosive performance against various targets
- Benefits:
  - Provides a much higher fidelity solution than current analytic/empirical methodologies to predict blast behavior and target response





Warheads Branch has the capability of characterizing blast pressure profiles of various explosives



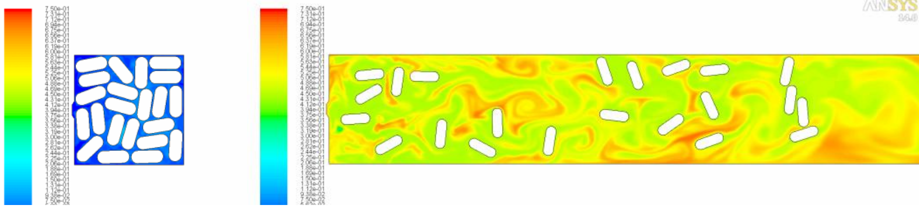
3D Internal Detonation Simulation for Structural Analysis

Alternative Propellant Burn Modeling Method

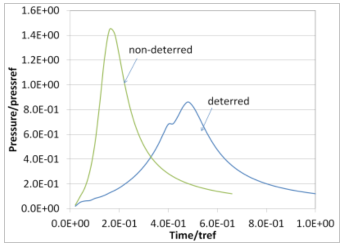
- Issue
  - ➢Need for alternative method to model propellant burn to study more detailed or specific condition/ phenomena
- Modeling Effort
  - ➢ Developed 2-D two-phase flow modeling technique that directly incorporates particles in the computational domain
    - ➢Local based calculation of burn rate around individual grain surfaces
    - ➢Multi-species gas generation based on local const. press adiabatic flame temp.
    - ➢Inclusion of effects of deterrent
    - ➢Incorporation of chemical kinetics with custom real gas mixture material model and chem. equil. calculations, includes rate equation integration

➢Benefits

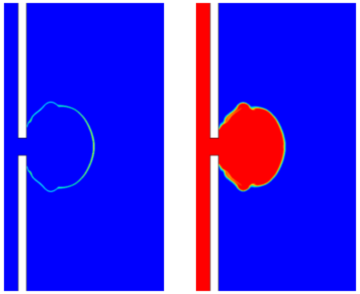
- ➢ Improved capability for studying localized, detailed effects, application to internal and external particle-gas interactions (w w/o chem. reactions) and particle impact based erosion and fouling



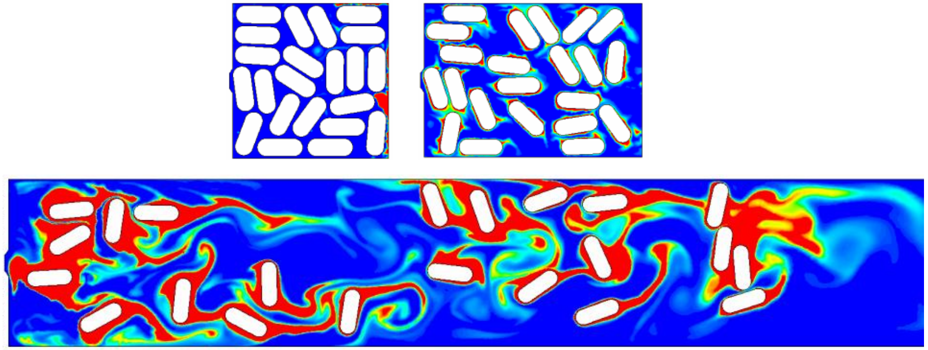
Multi-species gas generation – CO Mass Fraction



Inclusion of Deterrent Effects, effect on pressure



Chemically Reacting Flow Model, H2 escaping from tank, OH and H2 mass frac.



OH mass fraction development in reacting model

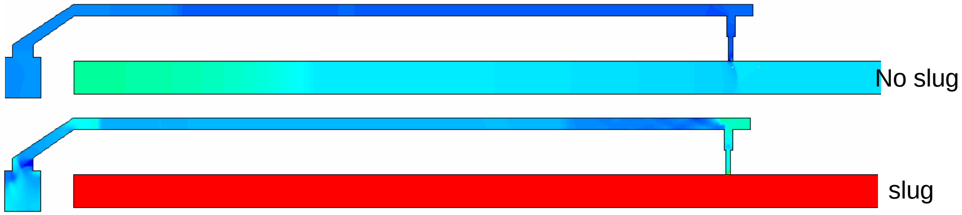
Laurie A. Florio

Computational Models of Gas and Particle Flow Characteristics in M4

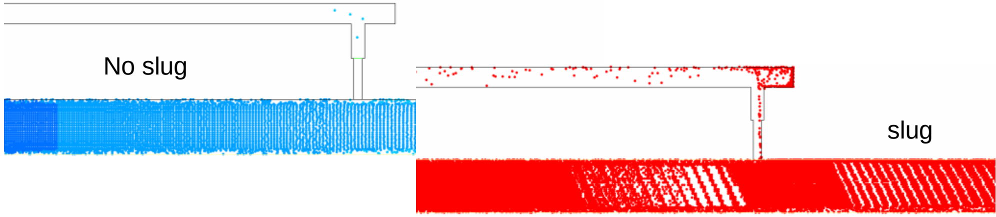
- Issue
  - ➢ Need to improve understanding of internal gas and particle flow characteristics in M4 firing blank and standard ammunition as related to fouling, erosion, and weapon operation
- Modeling Effort
  - ➢ Models of developed /used to analyze gas/particle flow in the following conditions
    - ➢Gas flow with and without slug
    - ➢Effects of particle type, particle release location, clearance space, slug on gas and particle flow and particle impact based erosion
    - ➢Sensitivity of gas conditions/weapon operation to typical effects of flow path erosion and fouling

➢Benefits

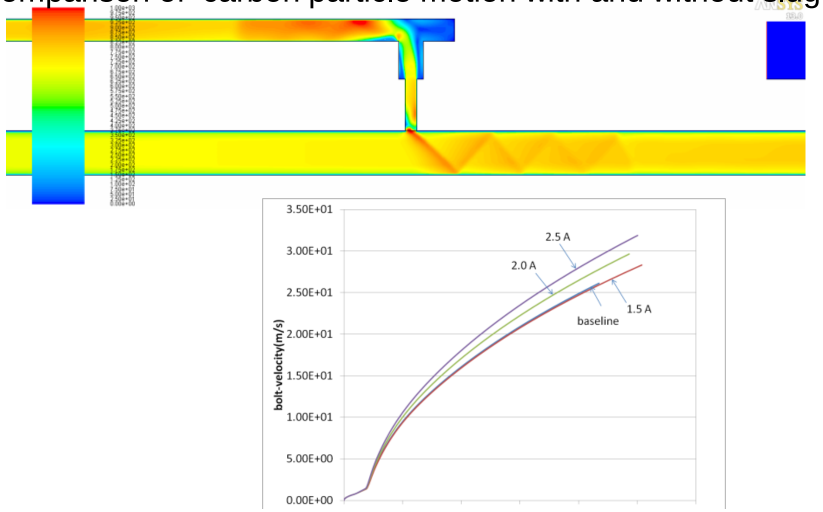
- ➢Ability to "see" transient gas flow, particle motion, estimate impact based erosion not readily captured in testing
- ➢Use information and tools to improve weapon design
- ➢Improve modeling capabilities and identify where further model development is needed



Comparison of pressures with and without slug



Comparison of carbon particle motion with and without slug



Effects of fouling and eroded flow paths on weapon operation: effect of increased port entrance area on bolt carrier motion

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Laurie A. Florio

CBE Tool Validation

- CBE tools need proper validation
- Picture compared to hardware
    - Weak validation
- Modeling the test and replicating measurable characteristics
    - Strong validation
    - Requires appropriate instrumentation
    - Limited by the capabilities of the test device
    - Limited by understanding of the loading
- Will discuss tools for gun hardening

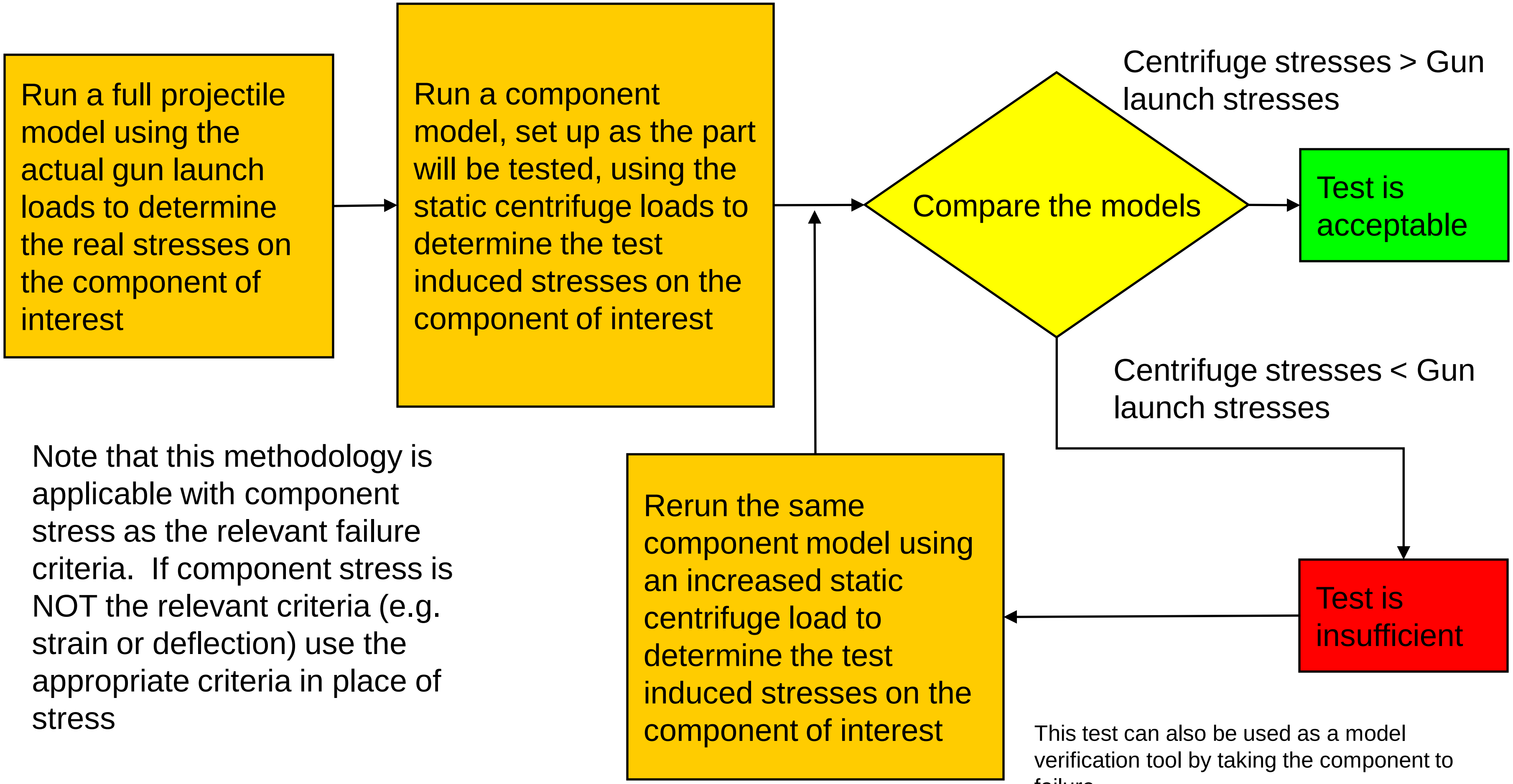
Gun Hardening Verification Tools

- Large number and variety
- Each has advantages and disadvantages
  - Used properly they are very effective at model validation and component qualification
- The key is understanding the gun environment and limitations of the tool
- Tools
  - Centrifuge
  - Static Load Cell
  - Shock Tower
  - Projectile firing
    - Standard gun launch
      - Impact
      - Soft recovery vehicle
    - Horizontal firing
    - Vertical firing
    - Canister firing
  - Ballistic Rail Gun (BRG)
  - Air Gun
  - Soft Catch System (SCat gun)
  - Hardware in the Loop (HWIL)

The Centrifuge

- It is possible to use a centrifuge for qualification or lot acceptance testing of components for gun launch applications
- Limitations
  - Replicating static load does not address the dynamic aspect of a gun launch
  - No direct correlation between static and dynamic loads
  - Component under test must be placed in a structure that is *equivalent* to how it will be mounted in a projectile
- Actual gun launches in the real structure are the ONLY sure way to assess component behavior
  - Expensive and time consuming
  - Soft recovery is one answer (but time and cost may still be a problem as well as altering the projectile dynamics)
- Developed a method to determine the relationship of centrifuge loads to gun launch loads to use the centrifuge as a screen
  - Not fool proof

Methodology for Specification of Acceptance Tests using a Centrifuge



Run a full projectile model using the actual gun launch loads to determine the real stresses on the component of interest

Run a component model, set up as the part will be tested, using the static centrifuge loads to determine the test induced stresses on the component of interest

Compare the models

Centrifuge stresses > Gun launch stresses

Test is acceptable

Centrifuge stresses < Gun launch stresses

Test is insufficient

Rerun the same component model using an increased static centrifuge load to determine the test induced stresses on the component of interest

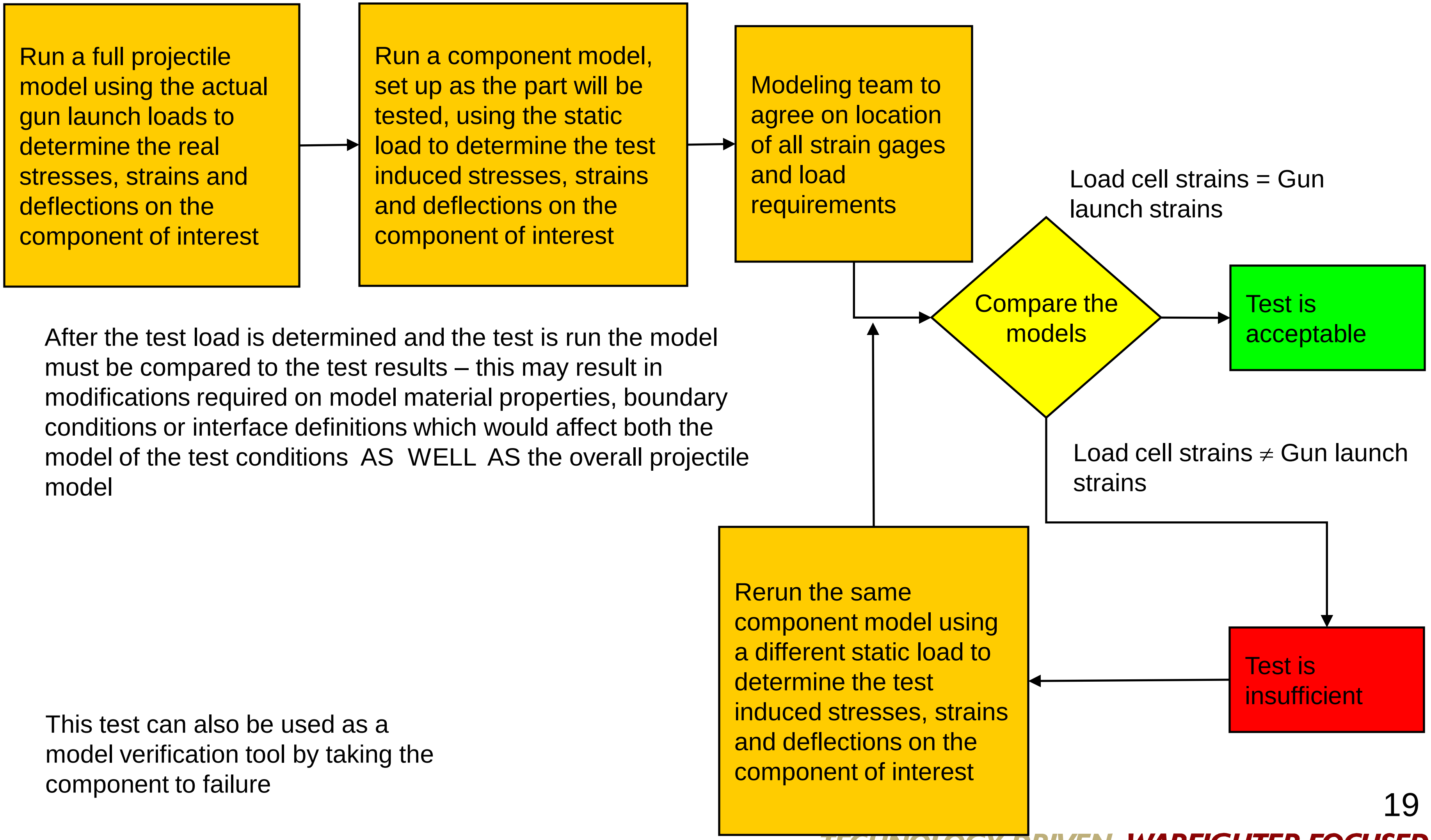
Note that this methodology is applicable with component stress as the relevant failure criteria. If component stress is NOT the relevant criteria (e.g. strain or deflection) use the appropriate criteria in place of stress

This test can also be used as a model verification tool by taking the component to failure

The Static Load Cell

- Static load cell (sometimes called a crush test) can be run in either tension or compression
- Test is used to check static analyses
- Cheap but requires experience on the part of the individual instrumenting the test article with strain gages
- Test loads must be verified with the analyst because projectile boundary conditions may be different
- Test is a great way of determining if interfaces in a model are behaving properly
- Test can be run to failure as a validation of design margin and model behavior
- Model MUST use the same boundary conditions as the test
  - It is acceptable to have different boundary conditions but this requires a model of both the test and the gun launch loading

Methodology for Specification of Tests Using a Static Load Cell



Run a full projectile model using the actual gun launch loads to determine the real stresses, strains and deflections on the component of interest

Run a component model, set up as the part will be tested, using the static load to determine the test induced stresses, strains and deflections on the component of interest

Modeling team to agree on location of all strain gages and load requirements

Compare the models

Load cell strains = Gun launch strains

Test is acceptable

Load cell strains ≠ Gun launch strains

Test is insufficient

Rerun the same component model using a different static load to determine the test induced stresses, strains and deflections on the component of interest

After the test load is determined and the test is run the model must be compared to the test results – this may result in modifications required on model material properties, boundary conditions or interface definitions which would affect both the model of the test conditions AS WELL AS the overall projectile model

This test can also be used as a model verification tool by taking the component to failure

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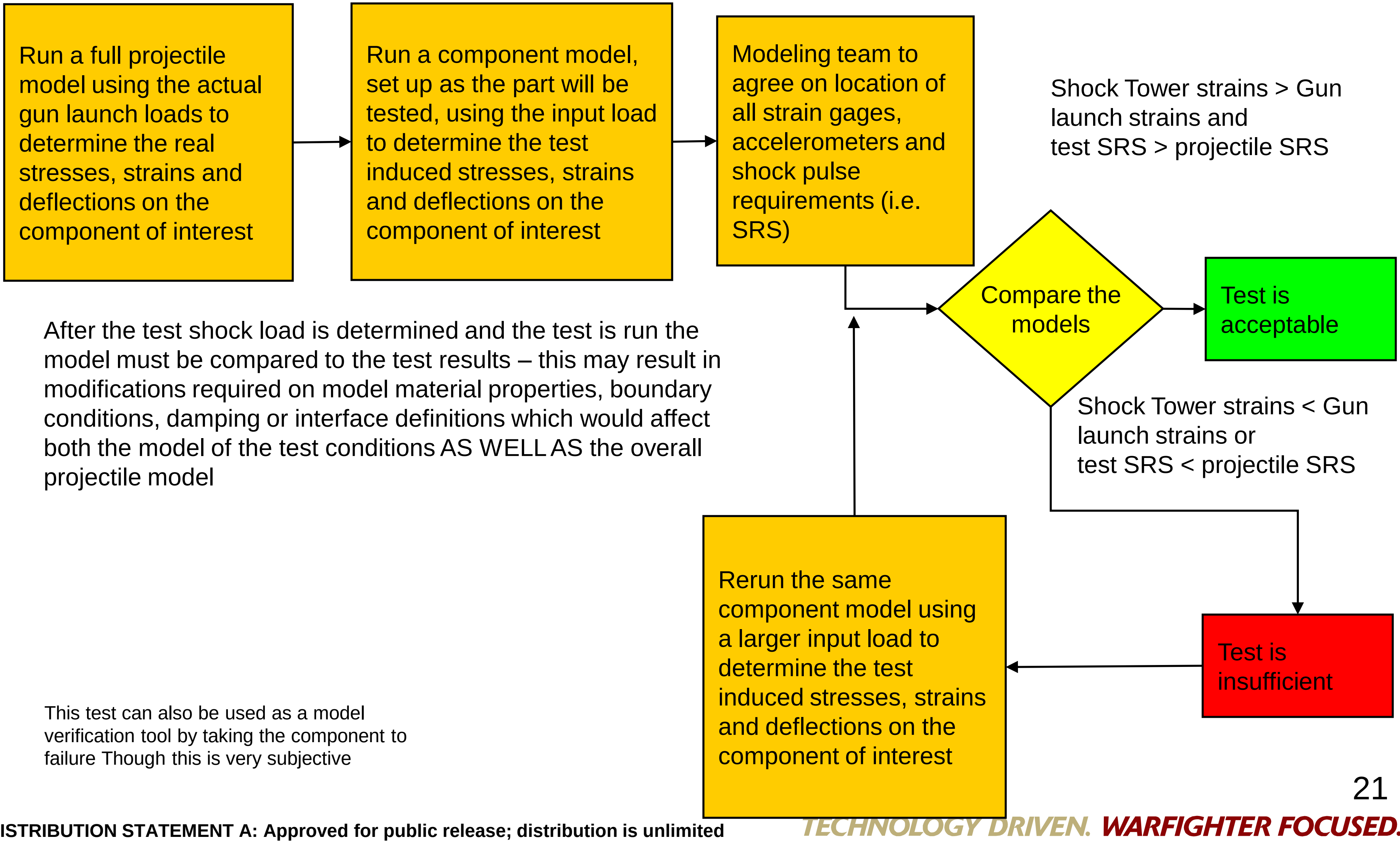
The Shock Tower

- Shock Tower is an excellent test device where short duration, high amplitude pulses can be tested
  - There is usually a weight and acceleration limitation
- Test is used to check dynamic analyses and can include both accelerometers and strain gages
- Cheap but again requires experience on the part of the individual instrumenting the test article
- Test loads must be verified with the analyst because projectile boundary conditions may be different
- Test is also a great way of determining if interfaces in a model are behaving properly in a dynamic sense
- Model MUST use the same boundary conditions as the test
  - It is acceptable to have different boundary conditions but this requires a model of both the test and the gun launch loading
- The shock response spectrum (SRS) of a the gun launch should be matched wherever practical

Methodology for Specification of Tests Using a Shock Tower



Run a full projectile model using the actual gun launch loads to determine the real stresses, strains and deflections on the component of interest

Run a component model, set up as the part will be tested, using the input load to determine the test induced stresses, strains and deflections on the component of interest

Modeling team to agree on location of all strain gages, accelerometers and shock pulse requirements (i.e. SRS)

Compare the models

Shock Tower strains > Gun launch strains and
test SRS > projectile SRS

Test is acceptable

Shock Tower strains < Gun launch strains or
test SRS < projectile SRS

Test is insufficient

Rerun the same component model using a larger input load to determine the test induced stresses, strains and deflections on the component of interest

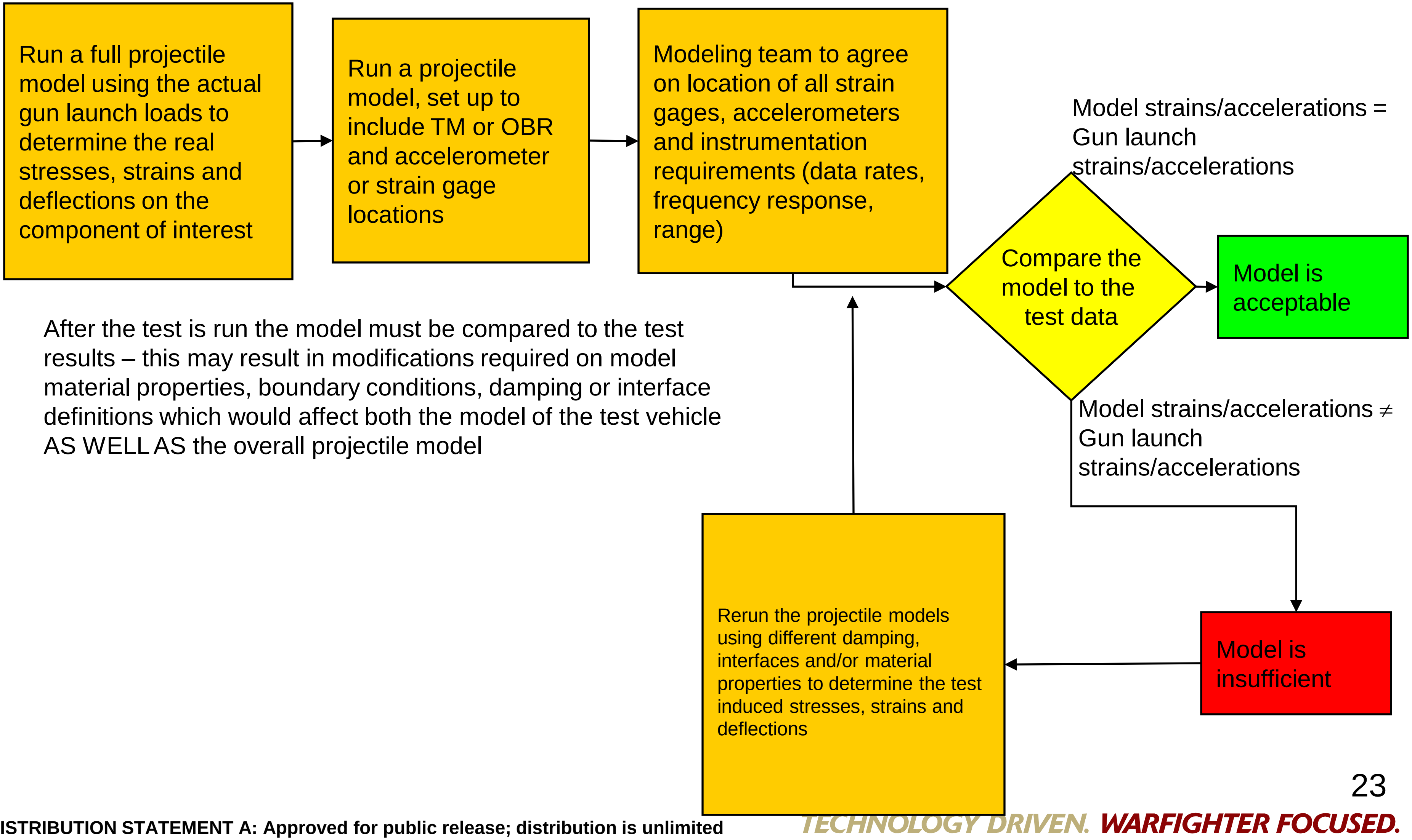
After the test shock load is determined and the test is run the model must be compared to the test results – this may result in modifications required on model material properties, boundary conditions, damping or interface definitions which would affect both the model of the test conditions AS WELL AS the overall projectile model

This test can also be used as a model verification tool by taking the component to failure Though this is very subjective

Projectile Firing to Impact

- Firing a projectile in the real weapon to determine if it functions properly is the best method IF
  - All agree up front that ground impact damage will be negligible (if you will blame failures on ground impact or if you know ground impact will result in an inability to assess damage then this is not a good method)
  - Variables data on components are taken before and after the firings so that yielding can be assessed in the models
    - This let's you know WHY you passed or failed a test
- Telemetry (TM) or On-Board Recorders (OBR) are great devices here but they do change the structural response of the projectile (i.e. you have to model them in the projectile)
  - TM is good because you have the data whether you find the projectile or not
    - You may lose the signal due to muzzle gas or interference
    - Issues with data rates
  - OBR's are good because you get high data rates and no interference
    - You have to find the projectile
    - The OBR has to survive ground impact
- The method is expensive and is a test of the instrumentation as well as the test article
- This test is used with yawsondes (described later) and a half muzzle brake to obtain stability information required for aeroballistic modeling

Methodology for Projectile Firing to Impact



Run a full projectile model using the actual gun launch loads to determine the real stresses, strains and deflections on the component of interest

Run a projectile model, set up to include TM or OBR and accelerometer or strain gage locations

Modeling team to agree on location of all strain gages, accelerometers and instrumentation requirements (data rates, frequency response, range)

Compare the model to the test data

Model strains/accelerations = Gun launch strains/accelerations

Model is acceptable

Model strains/accelerations ≠ Gun launch strains/accelerations

Model is insufficient

Rerun the projectile models using different damping, interfaces and/or material properties to determine the test induced stresses, strains and deflections

After the test is run the model must be compared to the test results – this may result in modifications required on model material properties, boundary conditions, damping or interface definitions which would affect both the model of the test vehicle AS WELL AS the overall projectile model

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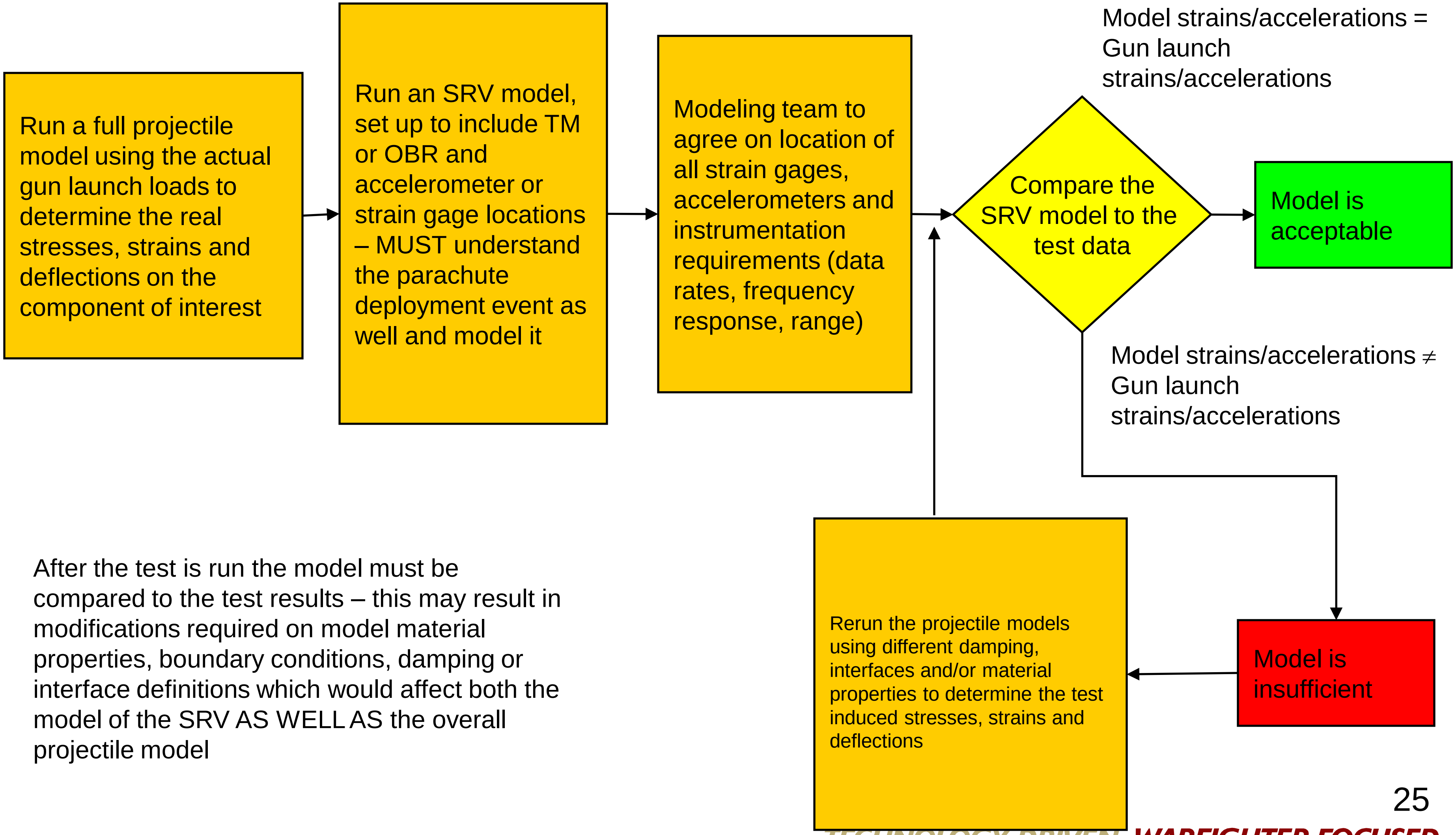
Projectile Firing - Soft Recovery Vehicle (SRV)

- If ground impact will damage critical components then a soft recovery projectile or soft recovery vehicle (SRV) is necessary
- It the past there have been two types of vehicles
  - Nose parachute systems – Vertical firing
    - Critical components in the mid-body or base
    - There is a design in work to allow nose mounted configurations
  - Base or mid-body parachute systems – Ballistic firing
    - Critical components in the nose or mid-body
  - Each vehicle can be instrumented with an OBR or TM if desired
- Vehicles are excellent test platforms BUT
  - They invariably change the dynamics of the projectile
  - Every firing is a test of the SRV reliability as well as the component reliability
  - They cost much more than a tactical gun firing
- Kineto-Tracking Mounts (KTM’s) are required if camera coverage is desired

Methodology for SRV Firing



Run a full projectile model using the actual gun launch loads to determine the real stresses, strains and deflections on the component of interest

Run an SRV model, set up to include TM or OBR and accelerometer or strain gage locations – MUST understand the parachute deployment event as well and model it

Modeling team to agree on location of all strain gages, accelerometers and instrumentation requirements (data rates, frequency response, range)

Compare the SRV model to the test data

Model strains/accelerations = Gun launch strains/accelerations

Model is acceptable

Model strains/accelerations ≠ Gun launch strains/accelerations

Model is insufficient

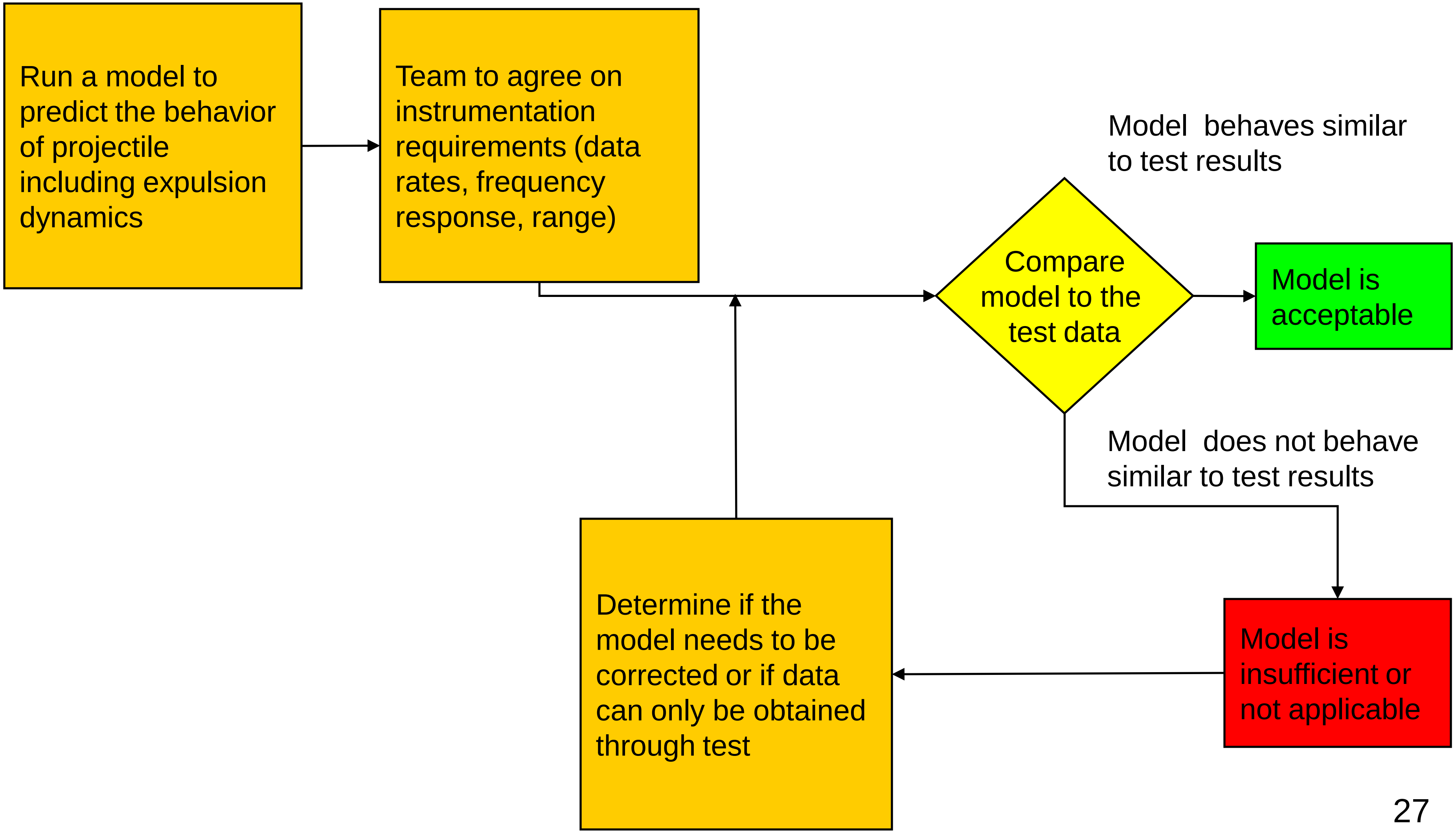
Rerun the projectile models using different damping, interfaces and/or material properties to determine the test induced stresses, strains and deflections

After the test is run the model must be compared to the test results – this may result in modifications required on model material properties, boundary conditions, damping or interface definitions which would affect both the model of the SRV AS WELL AS the overall projectile model

Horizontal Projectile Firing

- A Horizontal firing of a projectile is used to determine near gun effects or expulsion events where camera coverage must be obtained
  - Generally any parts recovered have to survive ground impact at an extremely high velocity
  - Excellent camera coverage can be obtained with Smear, Hadland and flight follower cameras
- Limitations with this type of testing are
  - The tests are more expensive than standard gun firings
  - Any deployment event will occur at a much higher dynamic pressure (velocity) and spin rate than a tactical firing
  - Cameras are exposed to any discarded materials
- Advantage is that you can obtain excellent camera coverage to resolve problems
- Typically no on-board instrumentation is used but OBR’s can work
- Can also fire into Hay Bales, Water with OBRs and/or TMs

Methodology for Horizontal Projectile Firing



Run a model to predict the behavior of projectile including expulsion dynamics

Team to agree on instrumentation requirements (data rates, frequency response, range)

Compare model to the test data

Model behaves similar to test results

Model is acceptable

Model does not behave similar to test results

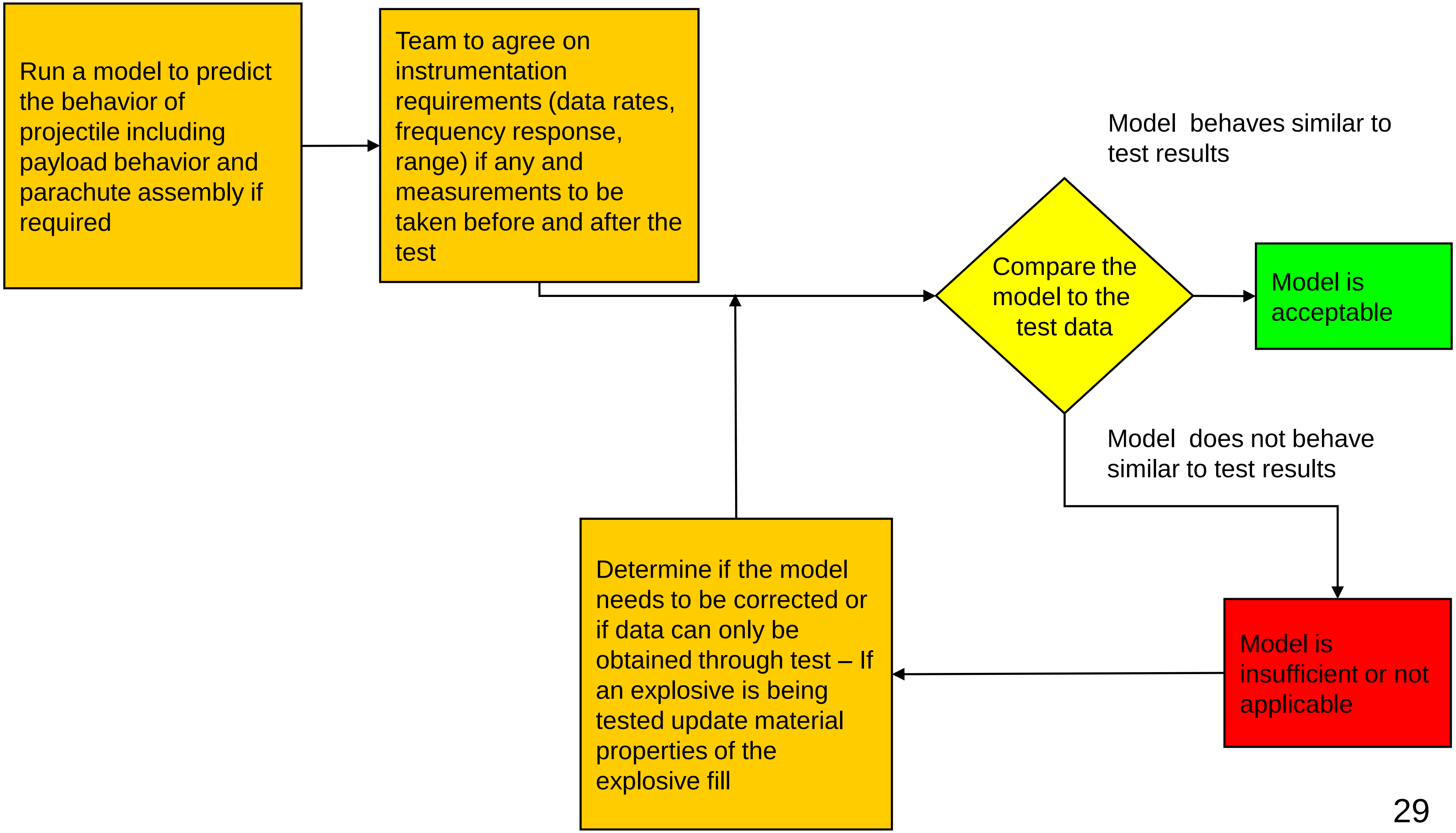
Model is insufficient or not applicable

Determine if the model needs to be corrected or if data can only be obtained through test

Vertical Projectile Firing

- A Vertical firing of a projectile is used to determine setback, spin and set-forward effects on items where a ground impact from a base down attitude is acceptable or a nose parachute is desirable
- Test can be done either with a parachute in the nose/ogive or the projectile can be allowed to hit “soft” ground base down
- Projectile must be fired at a Q.E. where it will “fail to trail” after maximum ordinate
- Limitations with this type of testing are
  - The airspace has to be cleared below 60,000- 120,000 ft
  - Parachute reliability (wraps and failure to deploy)
  - If no parachute is used you have to find the round
  - There can be no claim of impact damage
- Advantage is that you can fire actual HE fills to see the effect of launch on the explosive
- Typically no on-board instrumentation is used although TM and OBR’s could be
- A variation on this is firing into mud flats or shallow ocean (e.g. Shoeburyness, U.K.)

Methodology for Vertical Projectile Firing



Run a model to predict the behavior of projectile including payload behavior and parachute assembly if required

Team to agree on instrumentation requirements (data rates, frequency response, range) if any and measurements to be taken before and after the test

Compare the model to the test data

Model behaves similar to test results

Model is acceptable

Model does not behave similar to test results

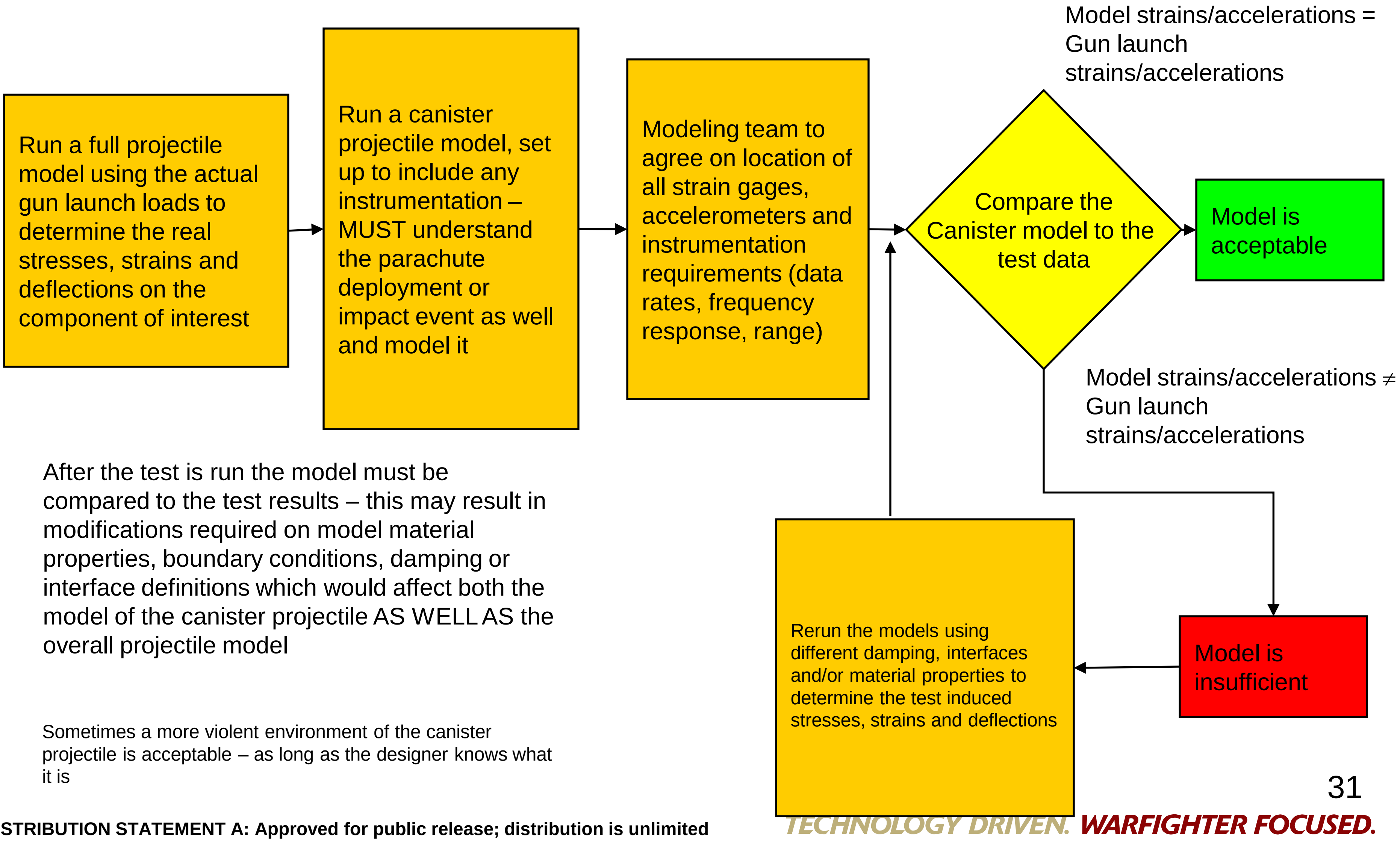
Model is insufficient or not applicable

Determine if the model needs to be corrected or if data can only be obtained through test – If an explosive is being tested update material properties of the explosive fill

Canister Projectile Firing

- In a canister firing a canister projectile is fired either with or without a parachute over either soft ground or water
- Canister projectile is large enough to hold the components under test
- Whole projectile sections may be tested if the canister projectile is large enough to house it
- Limitations with this type of testing are
  - Dynamically the canister is VERY different from an actual firing since the structure has been drastically altered
    - Requires the modeling of the test setup
  - Parachute reliability (wraps and failure to deploy)
  - If no parachute is used you have to find the round
    - Navy fires into water and recovers
  - There can be no cry of impact damage
  - Depending on the design of the canister an over test condition (maximum acceleration) may not be possible
- Advantage is that you can fire components that may fail catastrophically in the actual gun but the canister would keep the parts together for recovery and analysis
- Typically no on-board instrumentation is used although TM and OBR's could be

Methodology for Canister Firing



Run a full projectile model using the actual gun launch loads to determine the real stresses, strains and deflections on the component of interest

Run a canister projectile model, set up to include any instrumentation – MUST understand the parachute deployment or impact event as well and model it

Modeling team to agree on location of all strain gages, accelerometers and instrumentation requirements (data rates, frequency response, range)

Compare the Canister model to the test data

Model strains/accelerations = Gun launch strains/accelerations

Model is acceptable

Model strains/accelerations ≠ Gun launch strains/accelerations

Model is insufficient

Rerun the models using different damping, interfaces and/or material properties to determine the test induced stresses, strains and deflections

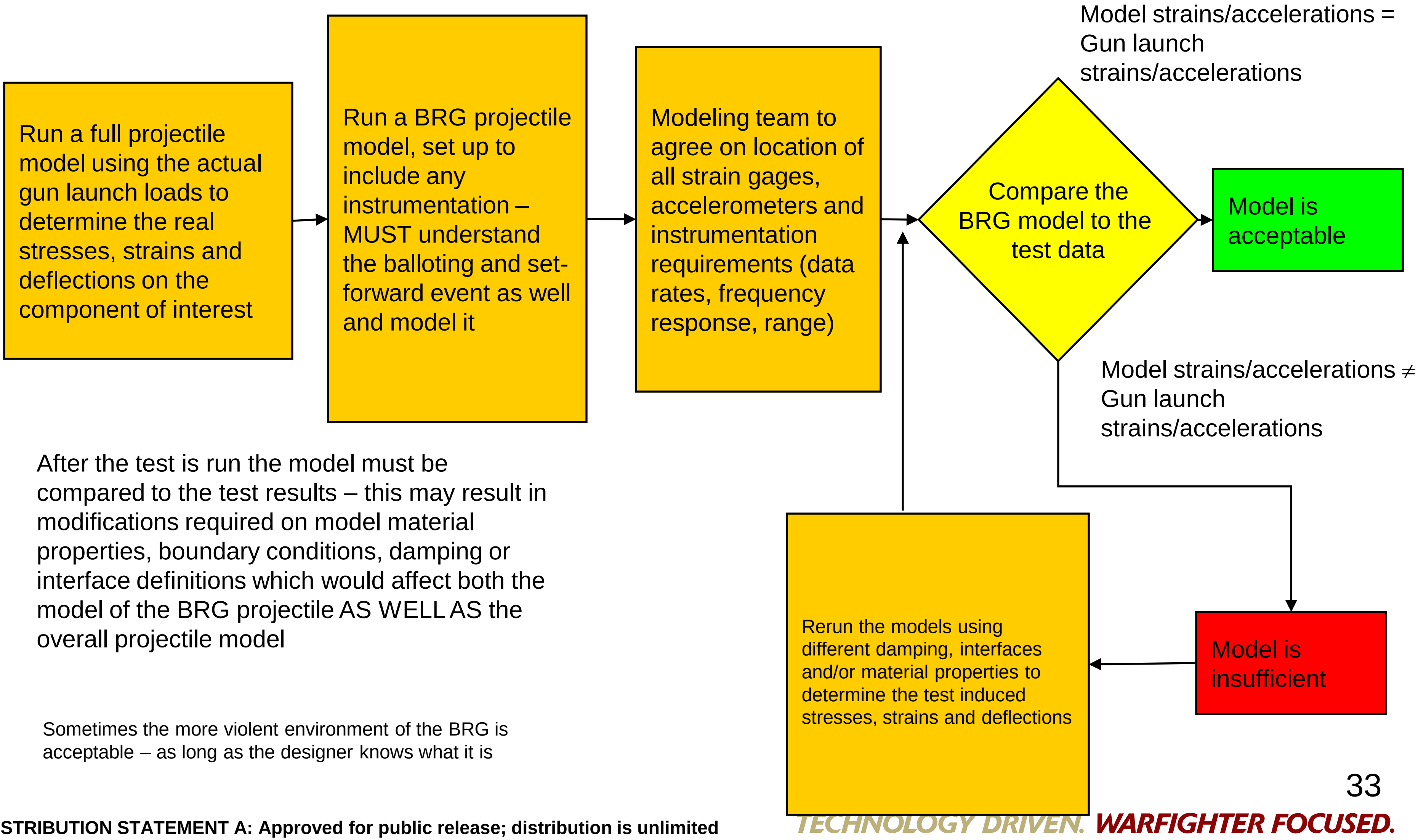
After the test is run the model must be compared to the test results – this may result in modifications required on model material properties, boundary conditions, damping or interface definitions which would affect both the model of the canister projectile AS WELL AS the overall projectile model

Sometimes a more violent environment of the canister projectile is acceptable – as long as the designer knows what it is

Ballistic Rail Gun (BRG) Firing

- BRG is very similar to a canister firing
- BRG projectile is large enough to hold the components under test
- There is a water scoop added to the front end of the projectile to decelerate the projectile in a water trough
- Gun will fire the projectile into a set of rails that keeps the projectile captured while forcing it to pass through ever increasing water depth in a trough
- Limitations with this type of testing are
  - Dynamically the BRG projectile is VERY different from an actual firing since the structure has been drastically altered
    - This requires the modeling of the test setup
  - There is additional balloting that occurs while the projectile transitions to and passes down the rails (this can be good sometimes)
  - There is an extreme set-forward acceleration as the projectile slows down in the water
  - Depending on the design of the BRG an over test condition (maximum charge) may not be possible
- Advantage is that you can again fire components that may fail catastrophically in the actual gun but the projectile would keep the parts together for recovery and analysis
- Typically OBR's are used so that the actual environment will be known

Methodology for BRG Firing



Run a full projectile model using the actual gun launch loads to determine the real stresses, strains and deflections on the component of interest

Run a BRG projectile model, set up to include any instrumentation – MUST understand the balloting and set-forward event as well and model it

Modeling team to agree on location of all strain gages, accelerometers and instrumentation requirements (data rates, frequency response, range)

Compare the BRG model to the test data

Model strains/accelerations = Gun launch strains/accelerations

Model is acceptable

Model strains/accelerations ≠ Gun launch strains/accelerations

Model is insufficient

Rerun the models using different damping, interfaces and/or material properties to determine the test induced stresses, strains and deflections

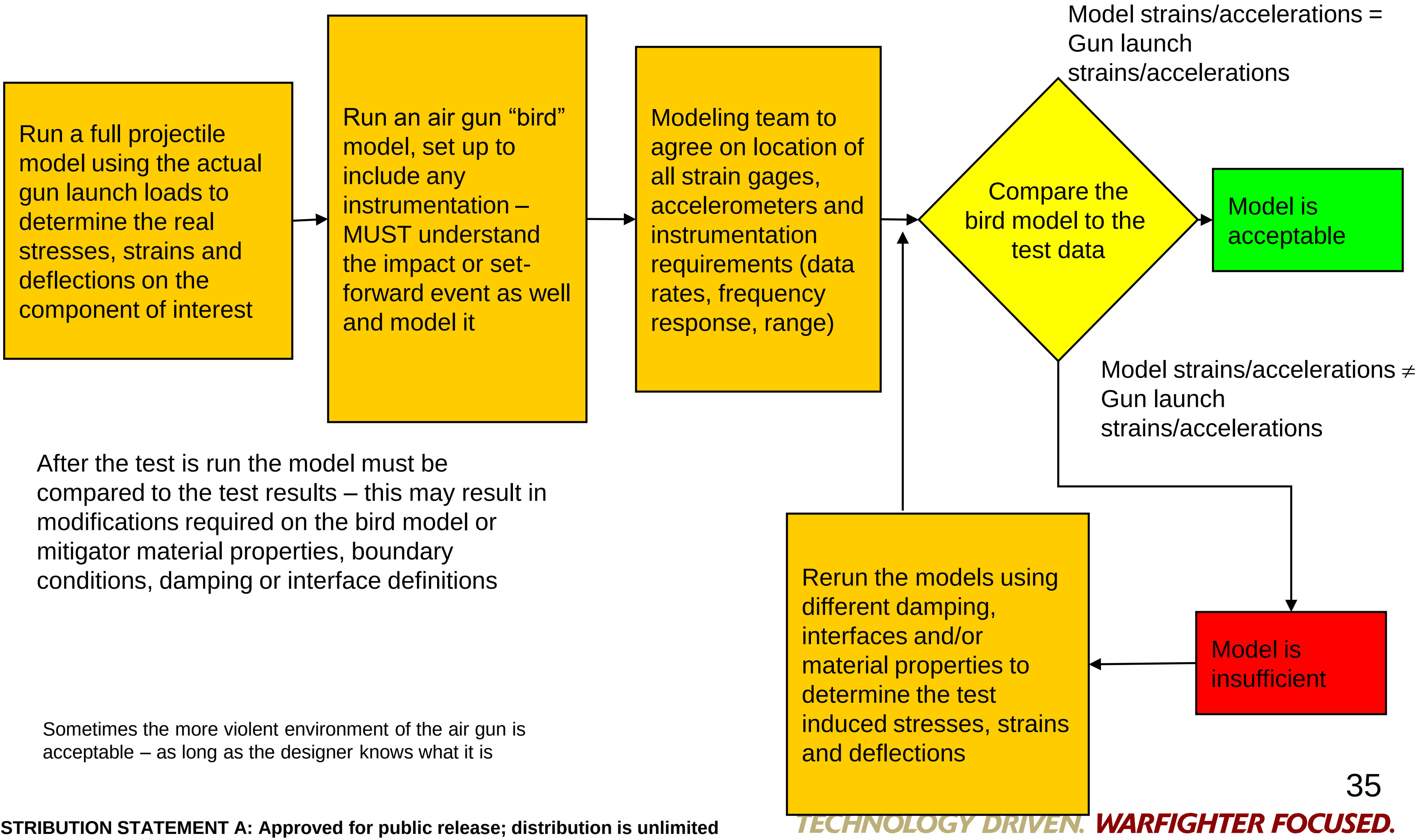
After the test is run the model must be compared to the test results – this may result in modifications required on model material properties, boundary conditions, damping or interface definitions which would affect both the model of the BRG projectile AS WELL AS the overall projectile model

Sometimes the more violent environment of the BRG is acceptable – as long as the designer knows what it is

Air Gun Firing

- In general there are two types of air guns
  - Compressed air charge guns
    - This type is a real gun in which a canister projectile is fired by compressed air into a recovery tube
  - Vacuum guns
    - In this type of gun the projectile is placed at the end of a long tube which is then evacuated – when the projectile is released it flies down the tube and impacts a mitigator which imparts the set-back event in reverse
- Both TM and OBR’s have been used with these devices
- In general only components can be tested
- The acceleration time curve is much sharper than a real gun and the input to the projectile (sometimes called a “bird”) contains large amplitude, high frequency spikes
  - This can be an advantage in the sense that the components will be stressed greater than in the real launch
- Projectile structure is also dynamically different than a real launch
- Parts are reusable and the tests are extremely inexpensive (about $2-5 K per shot)

Methodology for Air Gun Firing



Run a full projectile model using the actual gun launch loads to determine the real stresses, strains and deflections on the component of interest

Run an air gun “bird” model, set up to include any instrumentation – MUST understand the impact or set-forward event as well and model it

Modeling team to agree on location of all strain gages, accelerometers and instrumentation requirements (data rates, frequency response, range)

Compare the bird model to the test data

Model strains/accelerations = Gun launch strains/accelerations

Model is acceptable

Model strains/accelerations ≠ Gun launch strains/accelerations

Model is insufficient

Rerun the models using different damping, interfaces and/or material properties to determine the test induced stresses, strains and deflections

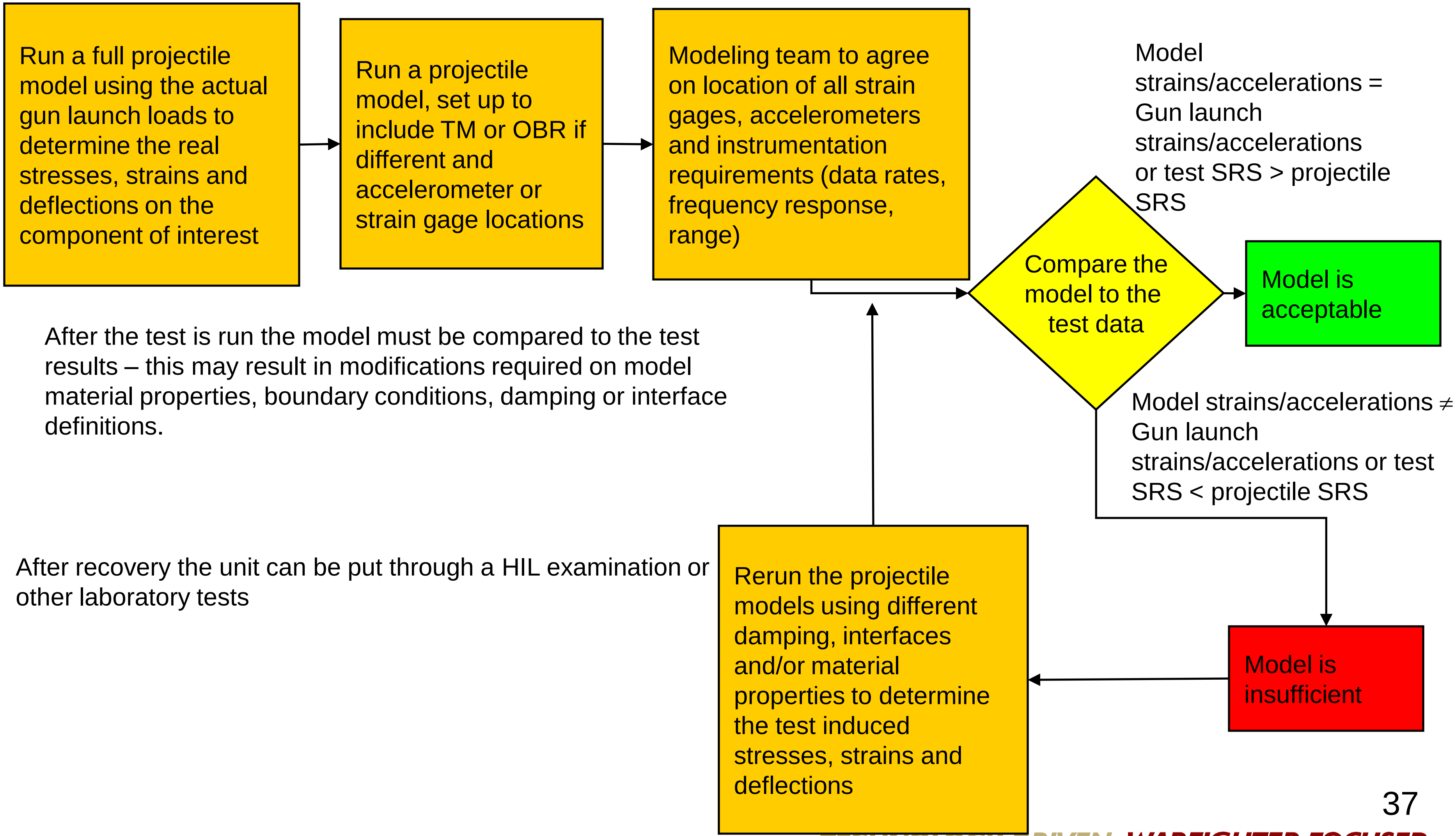
After the test is run the model must be compared to the test results – this may result in modifications required on the bird model or mitigator material properties, boundary conditions, damping or interface definitions

Sometimes the more violent environment of the air gun is acceptable – as long as the designer knows what it is

Soft Catch System (SCat)

- Soft Catch is a technique in which we fire a projectile from a real cannon into a deceleration tube
- In order for the tube to work properly any rotating band must be stripped off the projectile or any fins and discards must be locked down
- The projectile is then slowed down by high pressure air so that it can be recovered intact
- After recovery the parts may be examined or functioned in a laboratory environment
- Advantages of this system are
  - The actual projectile structure may be used
  - The firing occurs in a real weapon with a real charge
  - The hardware is recovered intact
  - The hardware can carry OBR’s or TM’s
  - The firing cost is low (about $8 k)
- Disadvantages are
  - More balloting may occur in the recovery system than in flight
  - No fin deployments or discards are possible
  - The projectile nose must be able to withstand the retarding pressures

Methodology for SRS/SCat Firing



Run a full projectile model using the actual gun launch loads to determine the real stresses, strains and deflections on the component of interest

Run a projectile model, set up to include TM or OBR if different and accelerometer or strain gage locations

Modeling team to agree on location of all strain gages, accelerometers and instrumentation requirements (data rates, frequency response, range)

Compare the model to the test data

Model strains/accelerations = Gun launch strains/accelerations or test SRS > projectile SRS

Model is acceptable

Model strains/accelerations ≠ Gun launch strains/accelerations or test SRS < projectile SRS

Model is insufficient

Rerun the projectile models using different damping, interfaces and/or material properties to determine the test induced stresses, strains and deflections

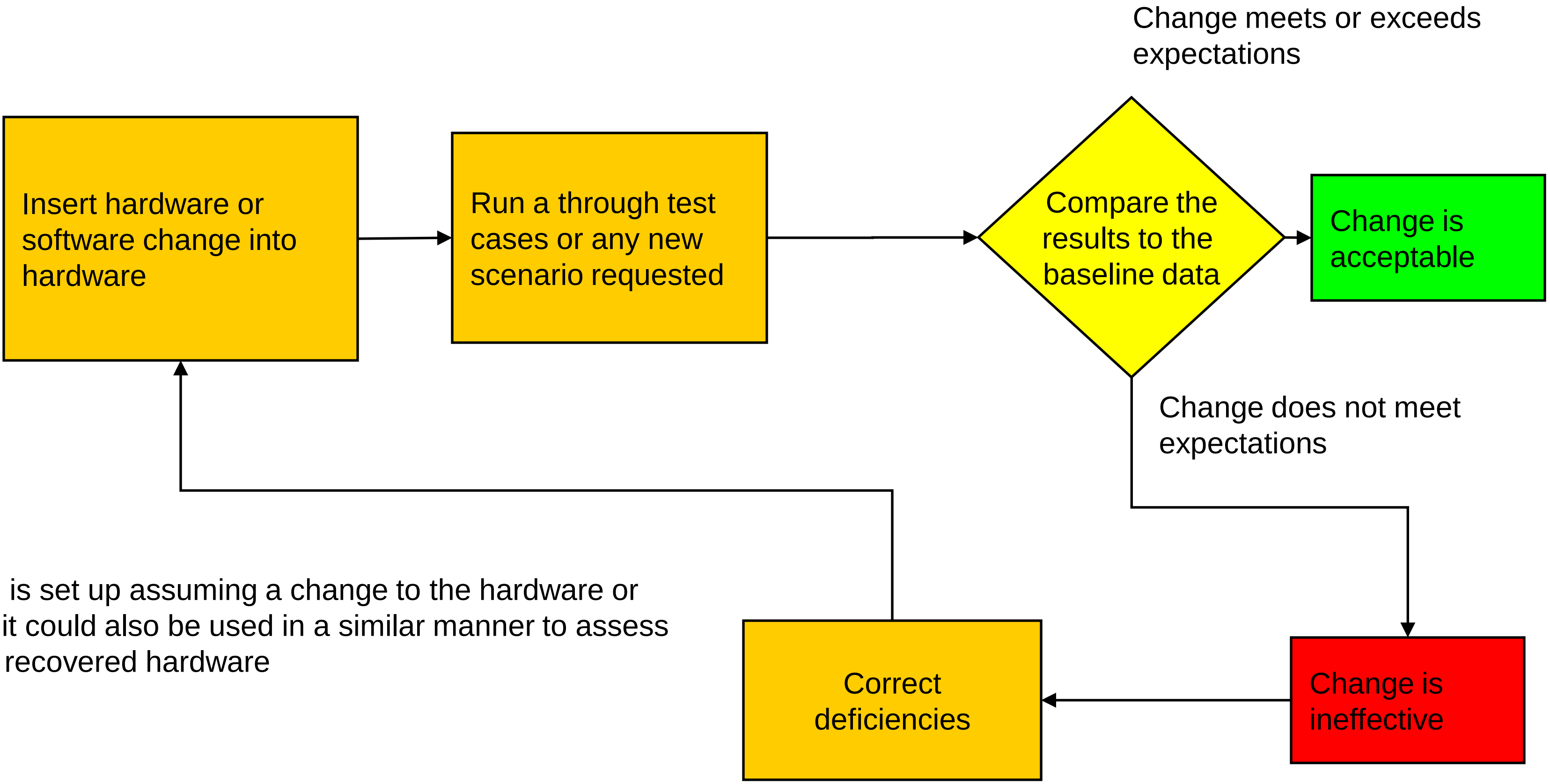
After the test is run the model must be compared to the test results – this may result in modifications required on model material properties, boundary conditions, damping or interface definitions.

After recovery the unit can be put through a HIL examination or other laboratory tests

Hardware in the Loop (HIL)

- A Hardware in the loop facility gives the designer the ability to put actual hardware through simulations in order to determine its response
- Extremely important if one is to evaluate how a damaged component would behave or if one wants to run many iterations of different conditions that would be cost prohibitive in a test environment
- The main issue with any HIL facility is validation
  - A large number of tests is usually required to assure the set up duplicates how the system would behave in the field
  - This can be very expensive because of the quality and quantity of test data required
- Once validated it is a very powerful tool
  - It can very cheaply and rapidly determine how a system will react to a new environment
  - It allows software as well as hardware changes to be evaluated quickly

Methodology for Validated HIL Use



Change meets or exceeds expectations

Insert hardware or software change into hardware

Run a through test cases or any new scenario requested

Compare the results to the baseline data

Change is acceptable

Change does not meet expectations

Change is ineffective

Correct deficiencies

This model is set up assuming a change to the hardware or software – it could also be used in a similar manner to assess damage to recovered hardware

Conclusions

- Talk focused on validation of structural models of gun launch components
  - Similar procedures can be developed for blast models, CFD, etc.
- Current practice at ARDEC for validation of models can come from a variety of tools
  - The validation methodologies for the available gun hardening tools have all been discussed
- CBE has time and again demonstrated huge cost savings once established and validated
  - In some cases the issue might never have been resolved

Thank You

Questions?