

**Integration of Ground and Flight Testing  
on F-35 Lightning II Program  
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# Acknowledgements

- **Robert J. Burt, F-35 Chief Structures Engineer**
- **Phil Gross, F-35 Deputy Chief Structures Engineer**
- **Pablo Guerrero, F-35 Structural Test Planning**
- **Marguerite Christian, F-35 Static Test Technical Lead**
  - *John Bradley, CTOL*
  - *Todd Bevan, CV*
  - *Jim Doyle, STOVL*
  - *Don Whiteley, STOVL*
- **Steve Owens, F-35 Structural Certification**



# F-35 Program Overview

- **Family of Three Air Vehicle Variants, with Similar Structural Arrangements**
  - *Each Variant is Designed To Satisfy the Requirements of a Separate Military Branch*
  - *F-35A = Conventional Take-Off and Landing (CTOL) Variant*
  - *F-35B = Short Take-off and Vertical Landing (STOVL) Variant*
  - *F-35C = Carrier Variant (CV)*
- **Simultaneous Development and Testing the Three F-35 Variants Provides Both Opportunities and Challenges**
  - *Opportunities – Commonality & Efficiencies*
  - *Challenges – Resource & Schedule Concurrency*



# F-35 Variant Planform Comparison



## STOVL



Span (ft)	35
Length (ft)	51.2
Wing Area (ft <sup>2</sup> )	460



## CTOL



Span (ft)	35
Length (ft)	51.4
Wing Area (ft <sup>2</sup> )	460



## CV



Span (ft)	43
Length (ft)	51.5
Wing Area (ft <sup>2</sup> )	667





# F-35 Structural Ground Test Program

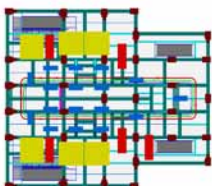
- **Full Scale Static & Durability Test of Each Variant**
  - *Six Full Scale Test Airframes*
  - *Four Commonly Designed Test Fixtures*
  - *CV Static Test Airframe Also Used as Drop Test/ Barricade/Live Fire Article*
- **Proof Tests Conducted on Each Variant's Loads Instrumented Flight Test Aircraft**
  - *Provides Larger Initial Flight Envelope*
  - *Reduces Early Flight Test Dependency on Static Test*

**F-35 Structural Test Program Is A Key Element of a Rigorous and Disciplined Structural Integrity Program**

# F-35 Full Scale Tests Locations & Fixture Sharing



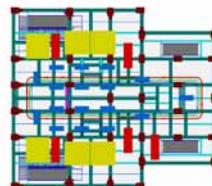
## LM Fort Worth, US



STOVL Static

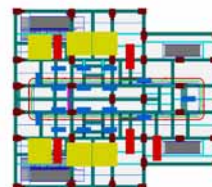


STOVL Durability



CV Static

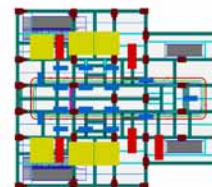
## BAES Brough, UK



CTOL Static

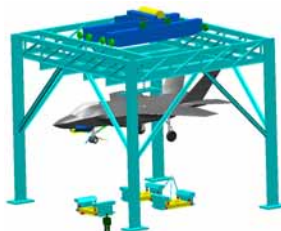


CV Durability



CTOL Durability

## Vought, Grand Prairie TX, US



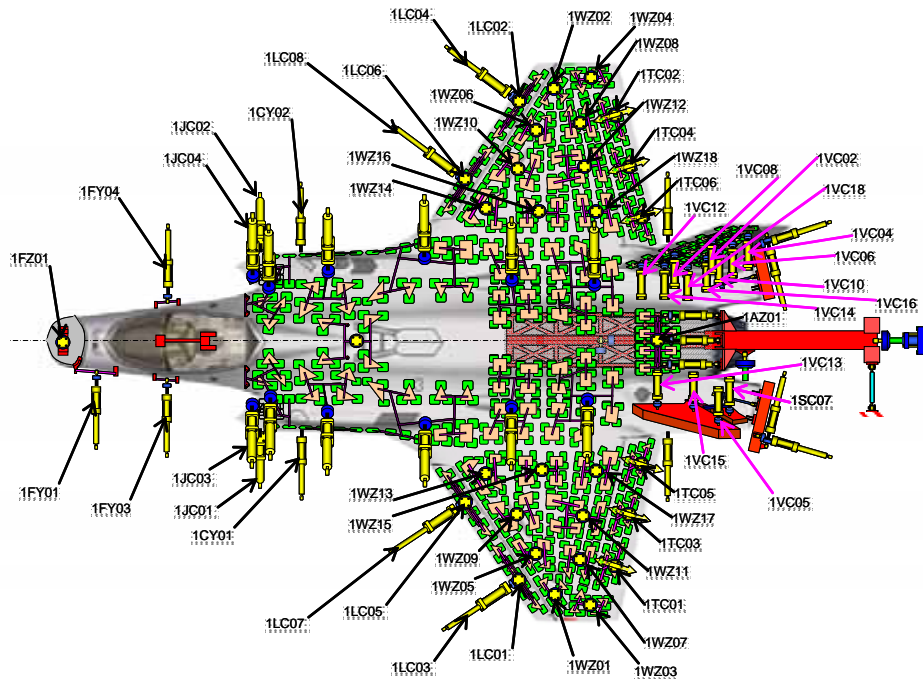
CV Drop



# Test Fixture Design Commonality Enabled by Structural Similarity



- Similarity of Airframe allows efficiencies in load arrangement design as well as load condition development
  - *Common Fuselage Bulkhead Stations*
  - *Similar Wing & Tail Box Planforms (STOVL & CTOL)*



View Looking Down on Upper Surface





# F-35 Load Case Selection Process

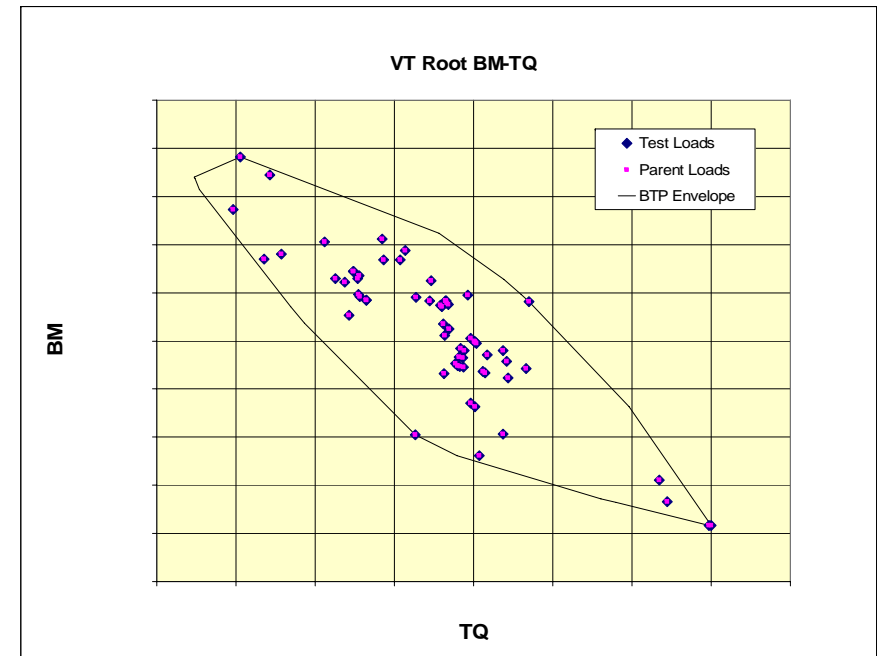
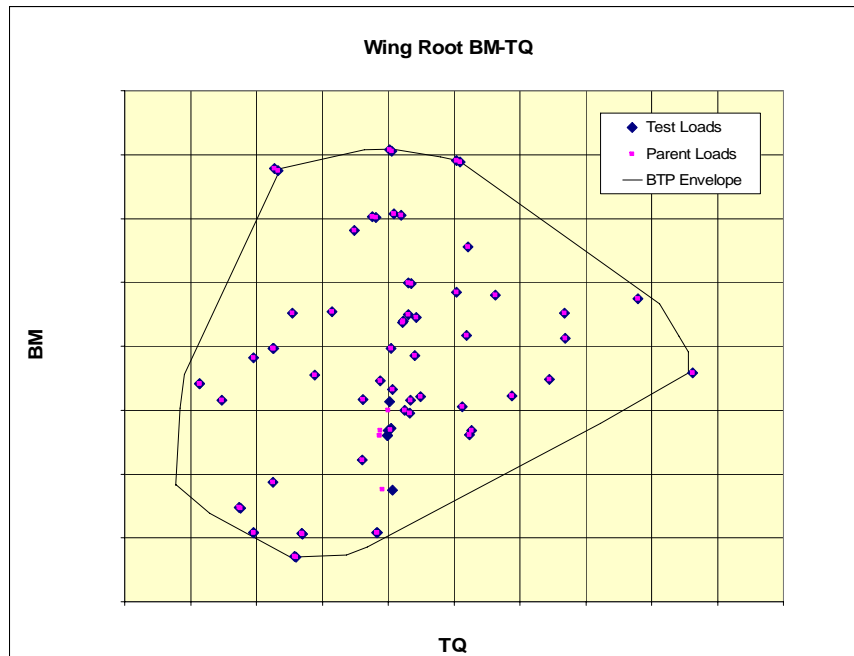
- **Comprehensive Set of Load Conditions Selected For Strength Certification of Each Variant**
  - *Selected to Exercise All Major Components, Control Surfaces, Weapons Hardpoints and Flight Opening Doors*
- **Two Independent Processes Used To Determine Candidate Load Cases For Static Testing**
  - ***External Loads Process***
    - External Load Envelopes At Specified Section Cuts Used To Identify Critical Loading Conditions
    - Provided Earlier Support for Test Fixture Design
  - ***Strength & Stability Margin Process***
    - Critical Margins And Failure Modes Reviewed to:
      - *Confirm Selections from External Loads Process*
      - *Referee Between Similar Conditions*
- **Candidate Load Conditions from the Two Processes Consolidated To Define Final Load Cases Considering:**
  - ***Structural Symmetry & Similarity***
  - ***Load Case Similarity***
  - ***Discrete Load Sources***





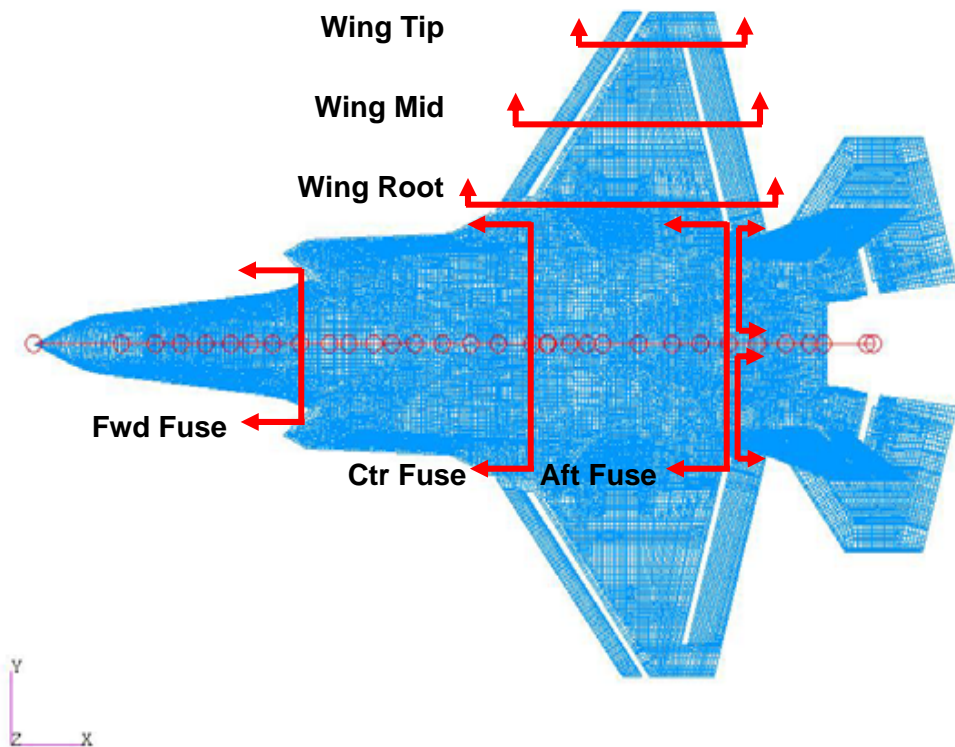
# External Load Case Selection Process

- 15 Integrated Load Envelopes Used in Selection Process
- Perimeter of the Load Envelopes Initially Selected to Provide Early Guidance For Test Fixture and Load Actuator Design (Over 100 Cases)
- Candidate List Selection Based on Knowledge of Primary Structural Drivers and Symmetry
  - *Reduced to 30 - 45 Conditions Depending on Variant*
  - *Load Arrangement Refined to Improve Match of Selected Conditions*

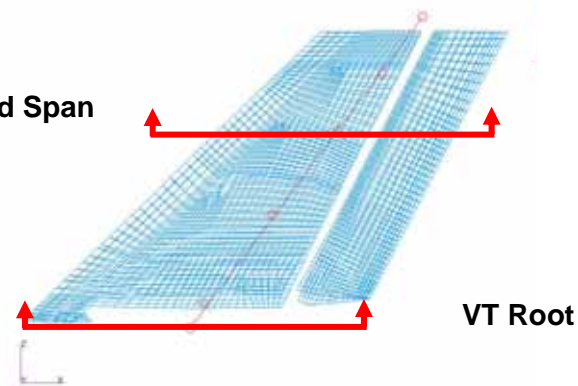




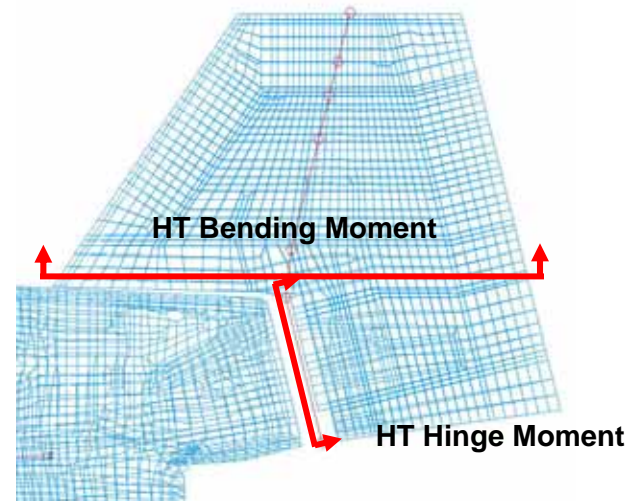
# External Load Section Cut Locations



VT Mid Span



HT Bending Moment

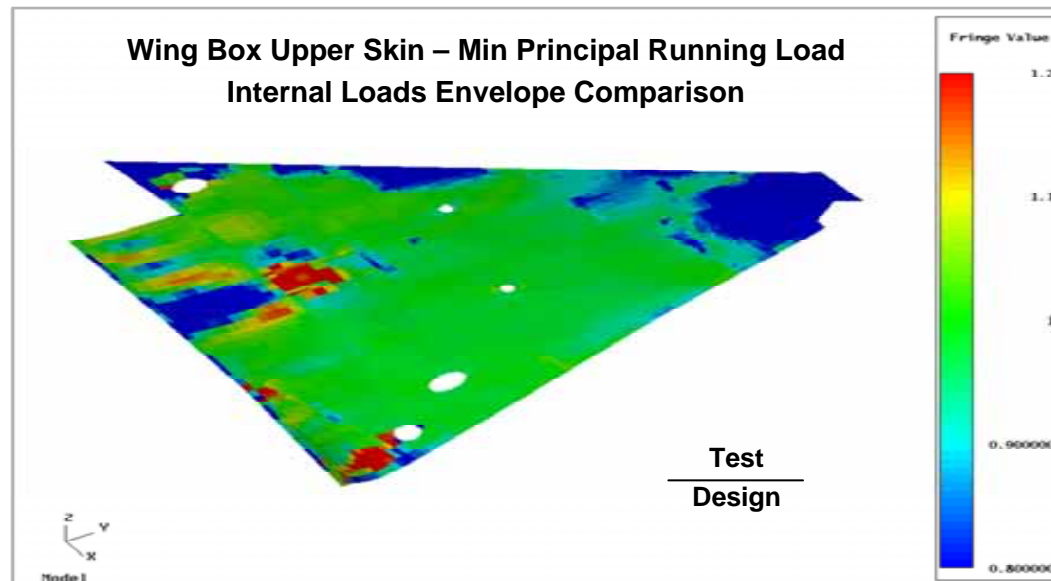


Control Surface Hinge Moments For LEF, TEF & Rudder Also Used

# Strength & Stability Margin Based Selection



- Each Structural Analysis Team Reviewed Their Stress Analysis for Critical Loadings
  - *Emphasis on Stability Related Margins*
  - *Preference to Conditions Which Drive Large Areas of Structure*
  - *Considered Only Loads Which Can Be Represented on Full Scale Static Test*
- Review of Critical Margins Confirms Adequacy of Envelopes Chosen for External Loads Review
  - *Used to Referee Between Similar Cases Near Envelope Perimeter*
  - *Ensures All Critical External Load Drivers Have Been Addressed*
    - Prompted the Evaluation of LHS and RHS Boom External Load Envelopes



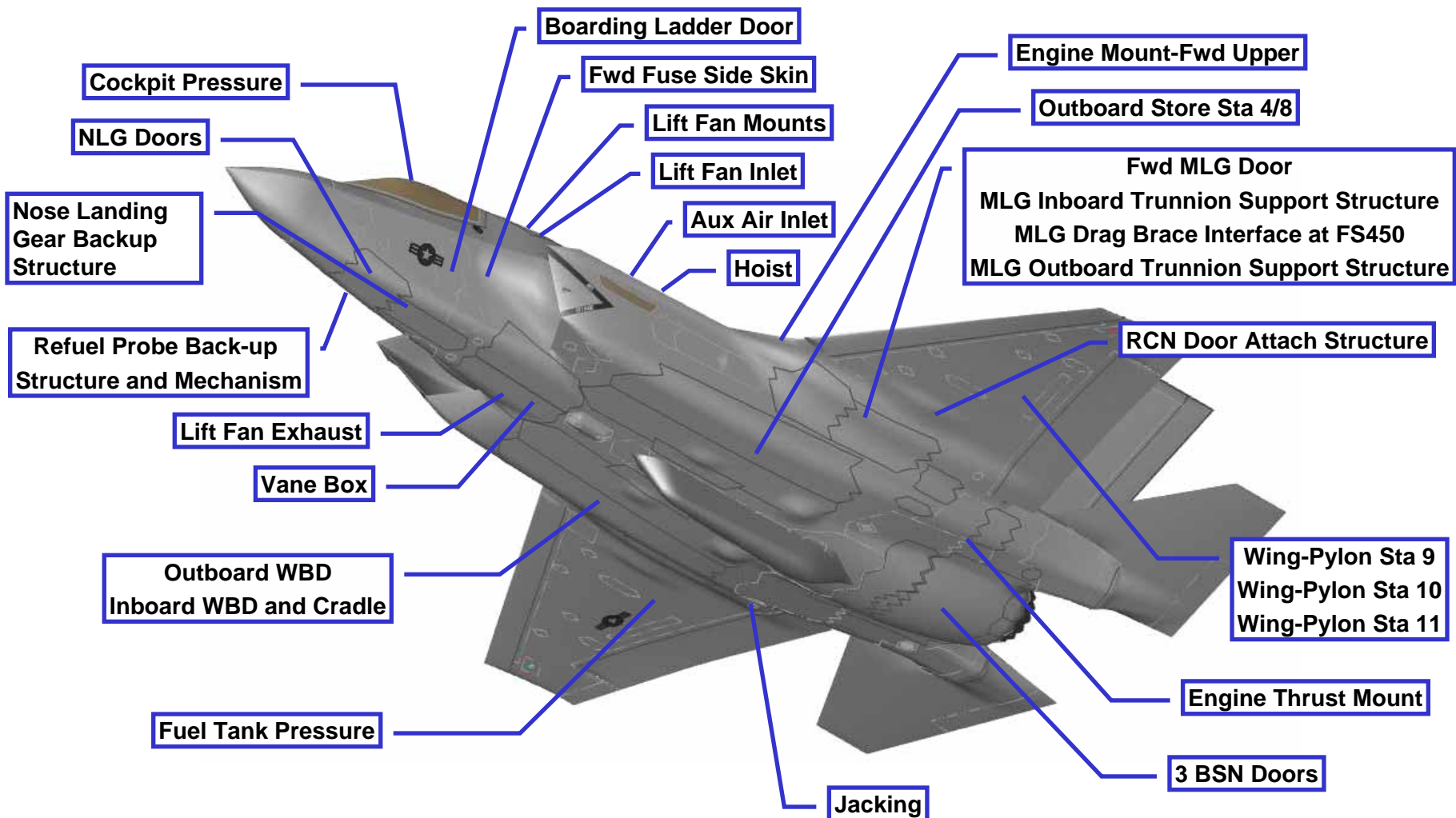


# CTOL Global Test Load Conditions

	Mach	Alt	Nz	Maneuver & Description	Wing				Fuselage						Tail				
					Wing Root	Wing Midspan	LEF	TEF	FF	CF	AF VBM/LBM	AF VBM/T	Booms	LH Boom	RH Boom	HT	VT Root	VT Midspan	Rudder
1	Med	SL	Min	RT - R Symmetric Pull-Up/Push-Over	X	X	X												
2	Med	SL	Max	RT - R Symmetric Pull-Up/Push-Over	X	X		X				X	X	X	X	X			
3	Med	SL	Max	RT - R Symmetric Pull-Up/Push-Over						X									
4	Med	SL	Min	RT - R Symmetric Pull-Up/Push-Over								X	X	X	X				
5	Med	SL	Man	RR - R 360 deg Roll, Full Rate	X							X					X		
6	Med	SL	Man	PL - L Roll Pull-Out, Full Rate			X										X		X
7	Low	SL	Max	A3 - Abrupt Pull-Up/Push-Over Type 3							X		X	X	X				
8	Med	SL	Max	RW - R Trim Open-Close Weapon Bay Doors					X										
9	Med	SL	Man	OL - L Yaw Gust								X		X		X	X		
10	High	Alt	Man	RR - R 360 deg Roll, Full Rate							X								
11	Med	SL	Man	RL - L 360 deg Roll, Full Rate	X	X													
12	Low	Alt	Man	RR - R 360 deg Roll, Full Rate							X	X	X		X				X
13	Med	SL	Max	RT - R Symmetric Pull-Up/Push-Over	X	X													
14	High	Alt	Man	RT - R Symmetric Pull-Up/Push-Over									X	X	X				
15	Med	SL	Min	RW - R Trim Open-Close Weapon Bay Doors	X	X	X												
16	High	Alt	Man	QL - L 180 deg Roll, Full Rate													X		X
17	Low	SL	Max	RT - R Symmetric Pull-Up/Push-Over			X					X	X	X		X	X		
18	Med	SL	Max	A1 - Abrupt Pull-Up/Push-Over Type 1	X	X				X									
19	Med	SL	Max	HS - Hammer Shock						X									
20	Med	SL	Man	PR - R Roll Pull-Out, Full Rate	X	X													
21	Med	SL	Man	QR - R 180 deg Roll, Full Rate				X											
22	Med	Alt	Man	RL - L 360 deg Roll, Full Rate							X	X	X	X					
23	Med	Alt	Man	RR - R 360 deg Roll, Full Rate							X	X	X		X				
24	Med	SL	Man	RR - R 360 deg Roll, Full Rate			X												
25	Med	SL	Man	QL - L 180 deg Roll, Full Rate							X								
26	Med	Alt	Man	RL - L 360 deg Roll, Full Rate					X	X							X		
27	High	Alt	Man	QL - L 180 deg Roll, Full Rate							X	X		X	X				
28	Med	SL	Man	SR-R Sideslip													X	X	



# STOVL Local Static Tests



# Structural Similarity Enables Cross-Variant Verification Testing



- **CV & CTOL**
  - *Weapons Bay Doors, RGA, & Backup Structure*
  - *Canopy*
- **STOVL & CTOL**
  - *Main & Nose Landing Gear Doors*
  - *Gear Door Uplocks*
- **STOVL & CV**
  - *Air Refuel Probe*
- **Tri-Variant**
  - *Engine Mounts*
  - *Wing Pylons & Hardpoints*



# Results of Load Case Selection



	CTOL	STOVL	CV*
<b>Fuselage Group</b>	<b>13</b>	<b>14</b>	<b>24</b>
<b>Wing Group</b>	<b>9</b>	<b>10</b>	<b>15</b>
<b>Tail Group</b>	<b>6</b>	<b>10</b>	<b>8</b>
<b>Total Full Airframe Cases</b>	<b>28</b>	<b>34</b>	<b>47</b>
<b>Local Tests</b>	<b>34</b>	<b>51</b>	<b>25</b>

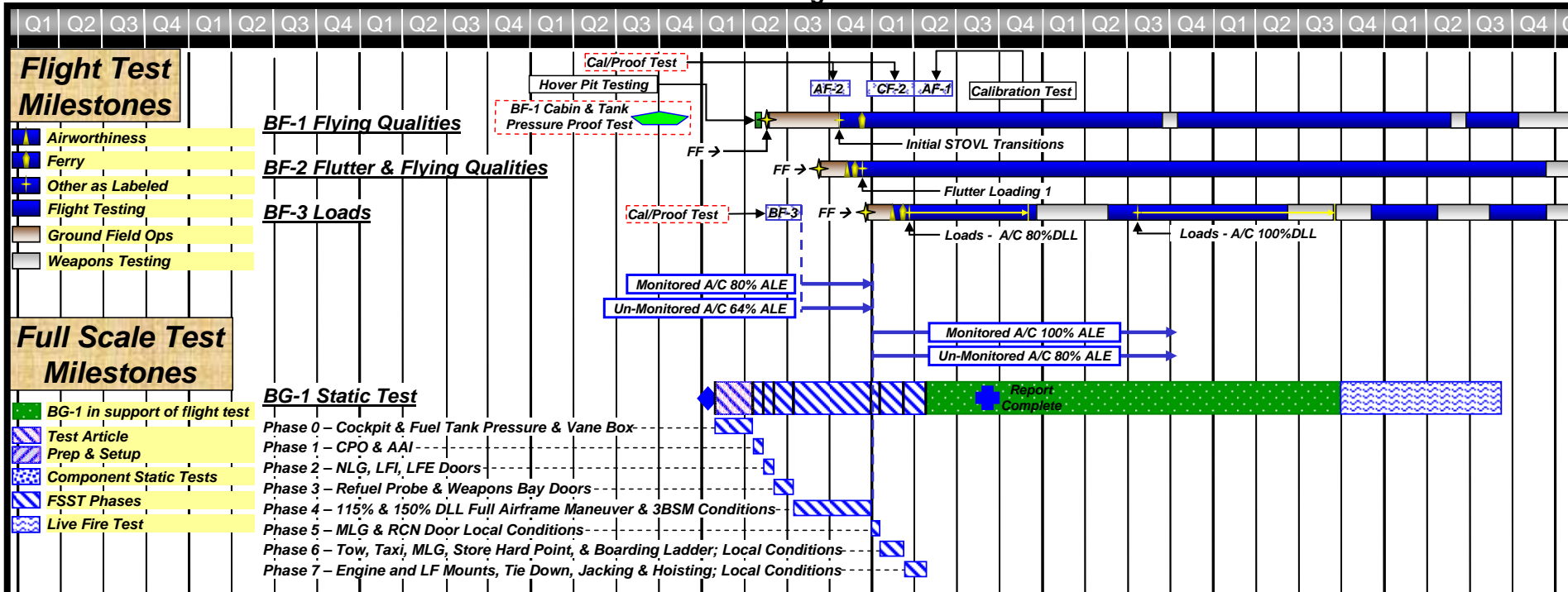
**\* CV Load Case Selections are Still Preliminary**



# F-35 Schedule Integration

- An Integrated Flight & Ground Test Program Has Been Developed
  - Key Flight Envelope Expansion Milestones Defined
  - Test Conditions Sequenced to Support Progressive Flight Clearance Build Up
  - Proof Testing Incorporated to Provide Early Flight Envelope to 80% DLL for Loads Monitored Aircraft

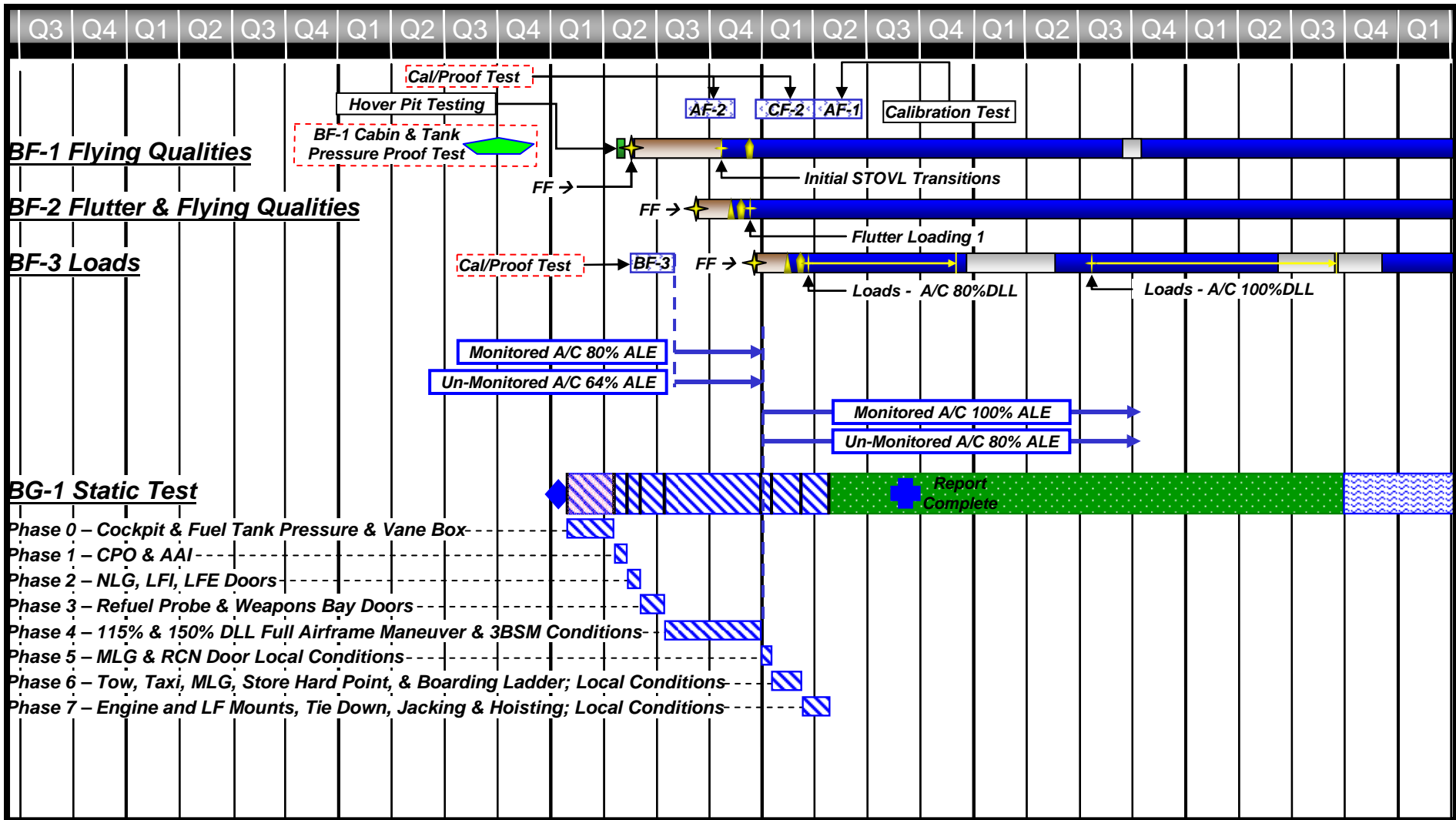
STOVL Ground and Flight Test Schedules





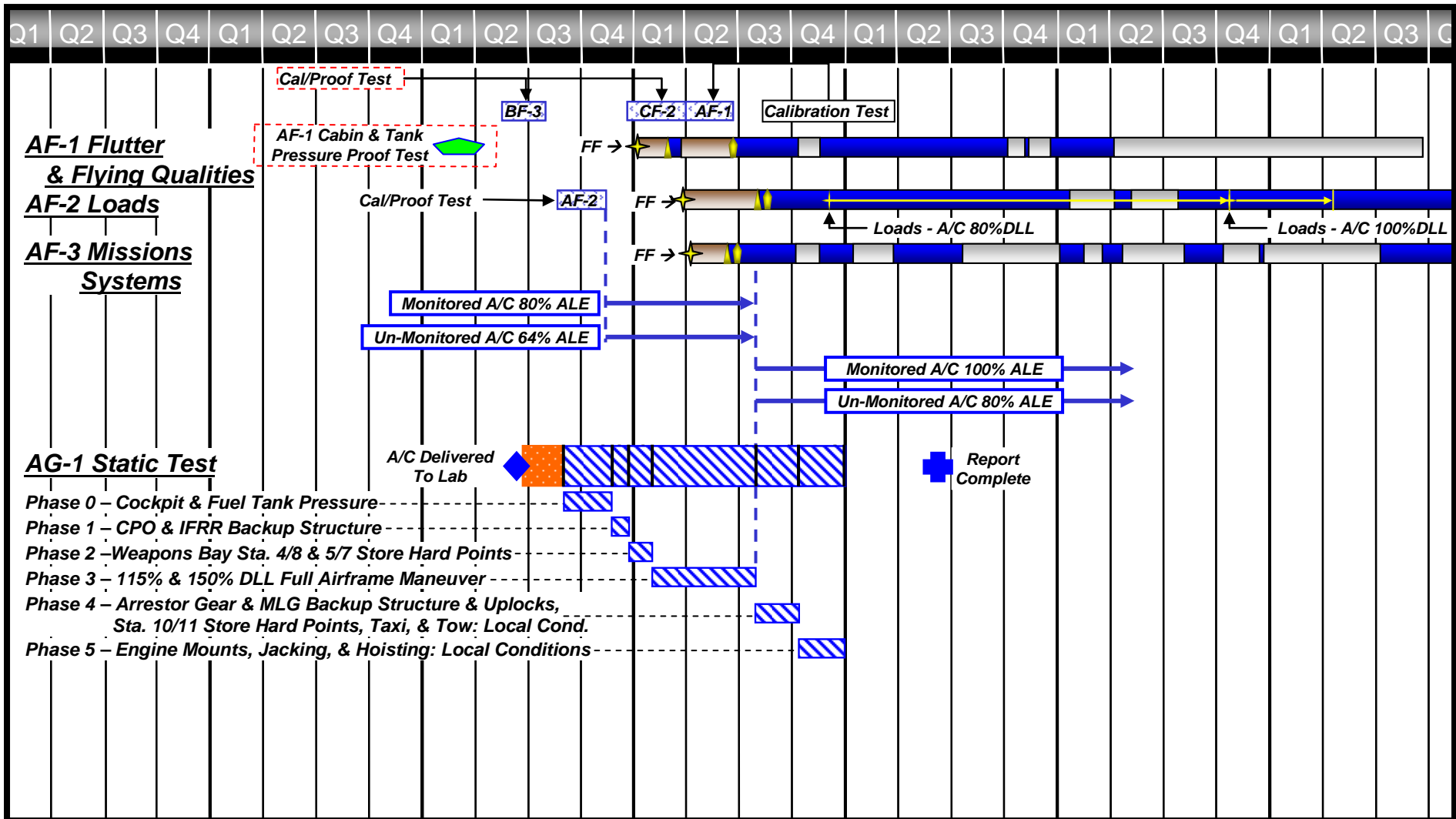


# Expanded View of STOVL Schedule



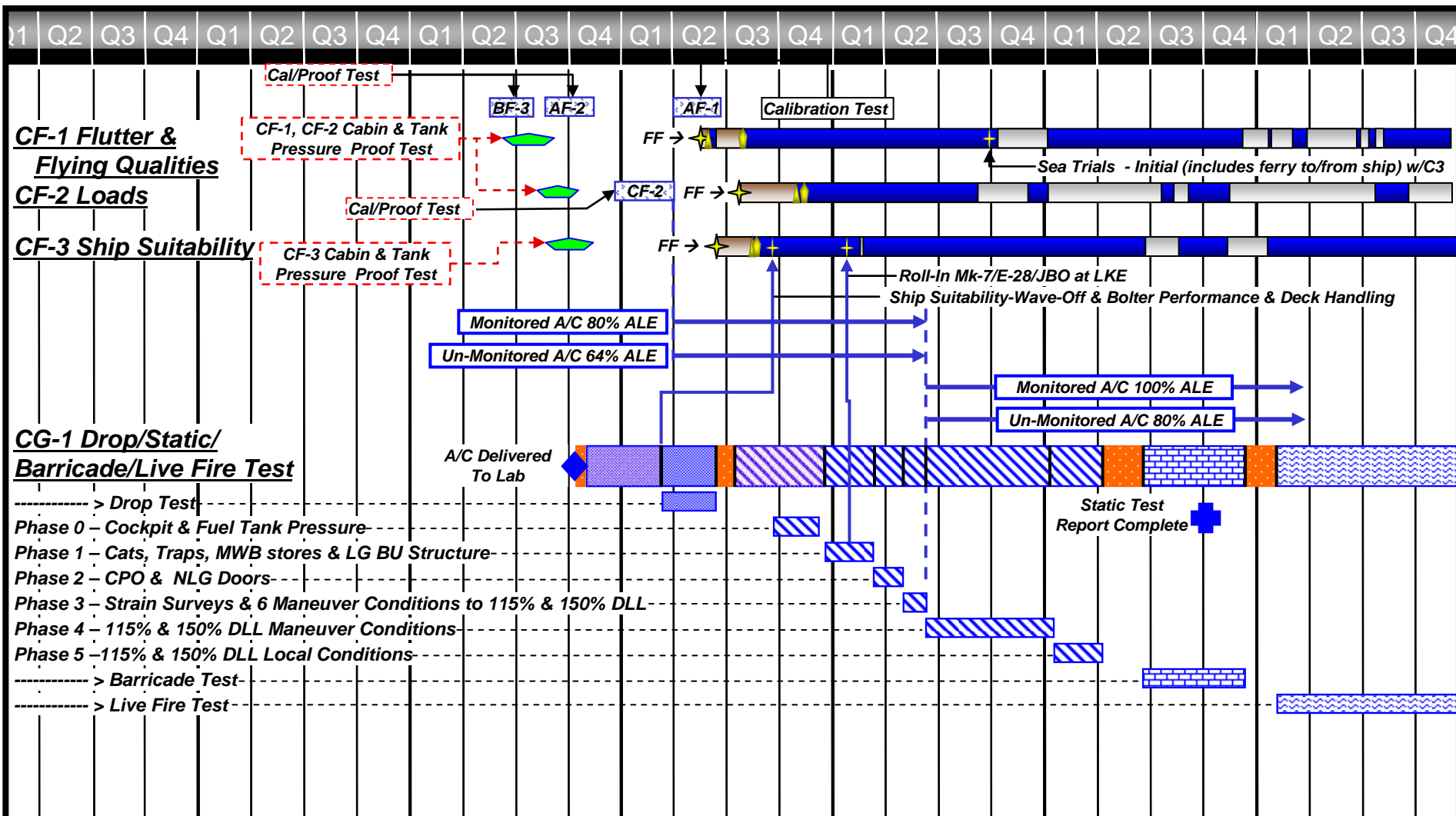


# Expanded View of CTOL Schedule





# Expanded View of CV Schedule





# Summary

- **F-35 Structural Test Program Benefits from Structural Similarity**
  - *Common Test Fixture Designs*
  - *Common Test Load Development Processes*
  - *Cross-Variant Verification Testing of Certain Structural Components*
- **Load Case Selection Process Ensures Static Test Adequacy**
  - *Earlier Support for Development of Test Arrangement*
  - *Additional Confidence in Resulting Selections*
- **Structural Test Program Developed to Support Flight Test Requirements**
  - *Test Conditions Are Deliberately Sequenced to Provide Timely Support for Key Flight Envelope Expansion Milestones*
  - *Proof Tests of the Loads Instrumented Aircraft Incorporated to Provide Earlier Flight Envelope Expansion*

**F-35 Structural Ground Test Program Has Been Developed as Part of a Thorough and Disciplined Structural Integrity Program**



# Questions

