Space Shuttle Orbiter-External Tank Forward Bipod Loads Analysis

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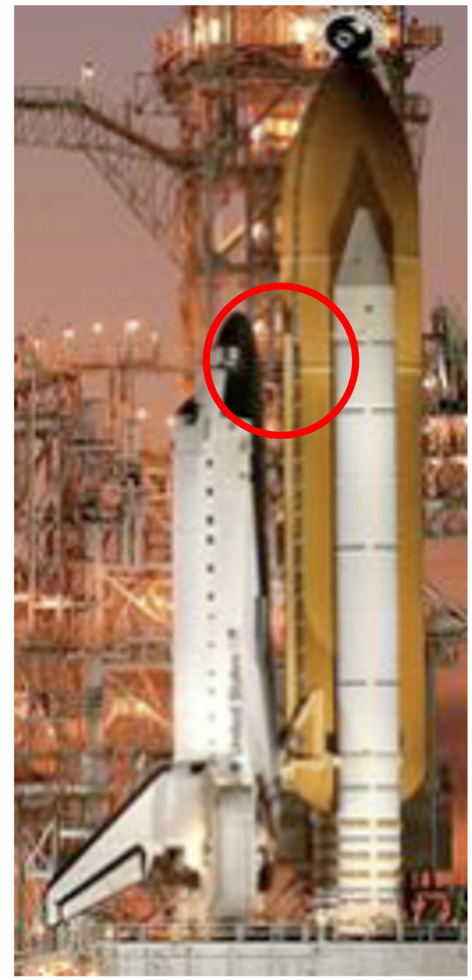
Space Shuttle OV-ET
Forward Bipod Loads Analysis

- Introduction and rationale
- Bipod description and schematic
- Load indicators
- Bipod structural tests
- Limit and ultimate loads envelopes
- Bipod tests to failure and analyses
- Expanded loads envelopes
- Concluding remarks

Forward Bipod Connects Space Shuttle Orbiter (OV) To External Tank (ET)

Application Of Shuttle Forward Bipod To Future Launch Vehicles

- Support planned transition from **Shuttle** to Constellation Program vehicles
- Interim "Shuttle-derived" launch vehicle
    + Cargo variant with 3xSSME and side-mount payload pod
        * Higher mass and ascent loads than Shuttle
- Does existing Forward Bipod have any additional loads capability?
    + Significant time and cost savings if it does…



Application Of Shuttle Forward Bipod To Future Launch Vehicles (2)

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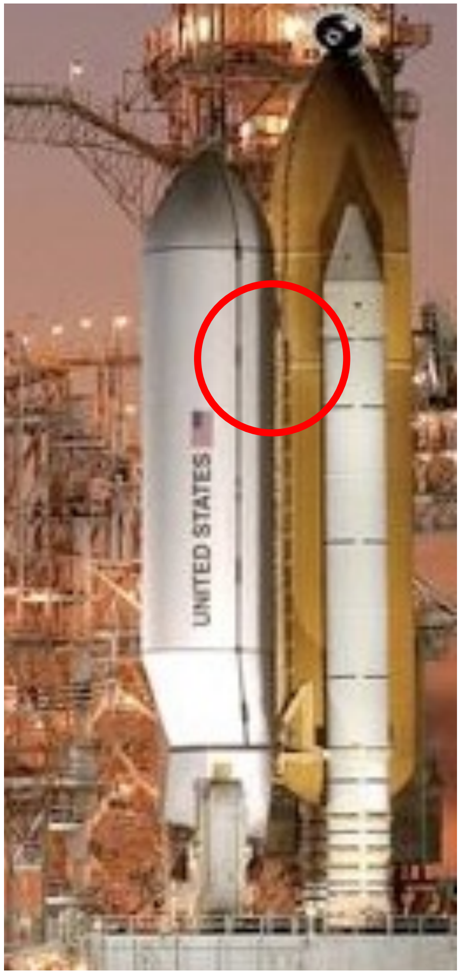
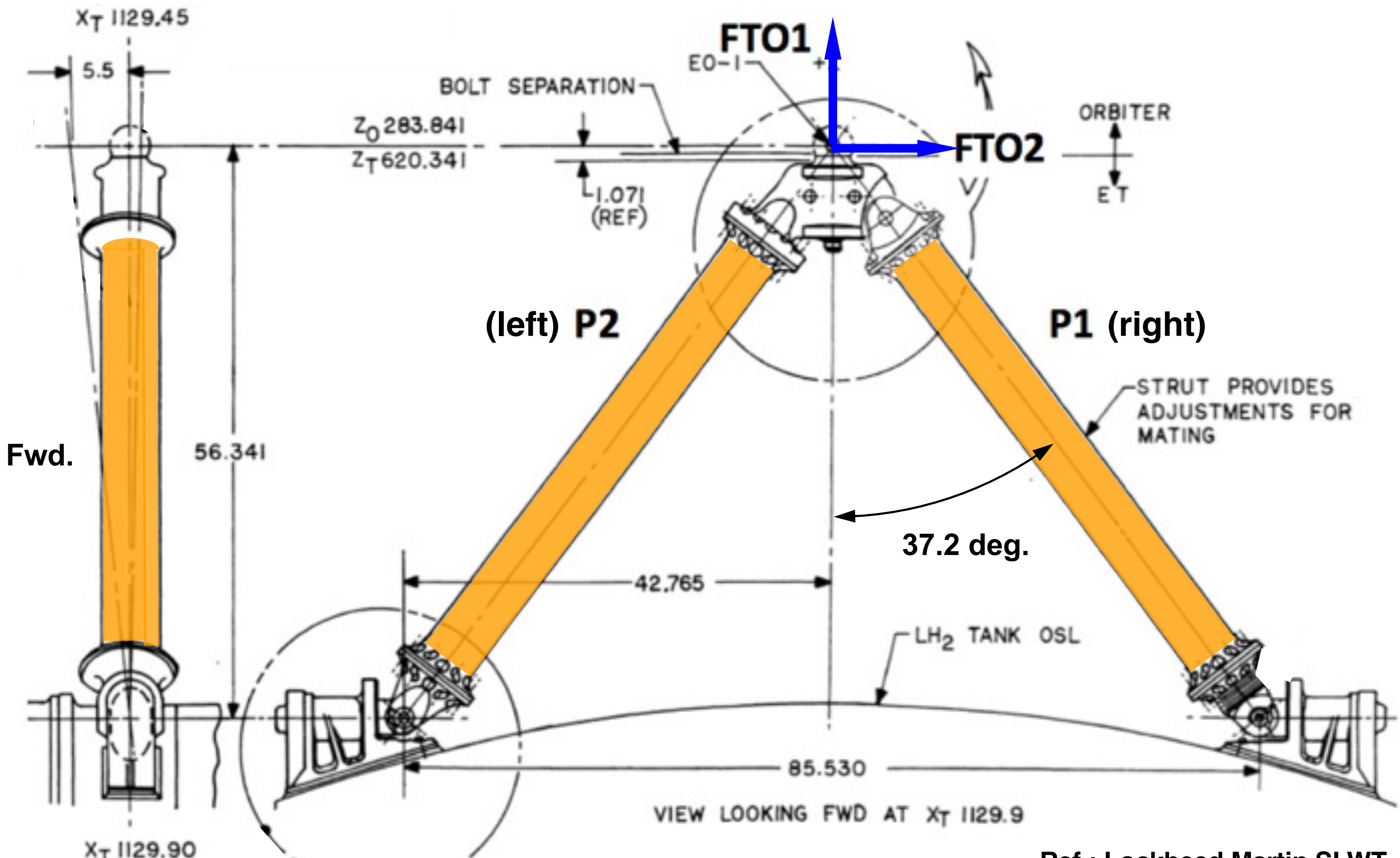


Space Shuttle OV-ET Forward Bipod Description

- Space Shuttle Orbiter and ET connected 3 places with statically determinate “truss” arrangement
  + Reduces OV-ET interface loads
- Forward Bipod attachment at X_T = 1130 in.
  + Explosive bolt through apex
    * OV interface/separation at MECO
  + ET interface allows transverse rotation of Bipod w.r.t. ET
    * Decouple OV from ET thermal effects during pre-launch fill of cryoprops
- Tests and analyses performed to estimate actual capabilities of Bipod interface

Forward Bipod Schematic



Ref.: Lockheed Martin SLWT Syst. Def'n. Hdbk, Dec. 1997

Bipod Load Indicators

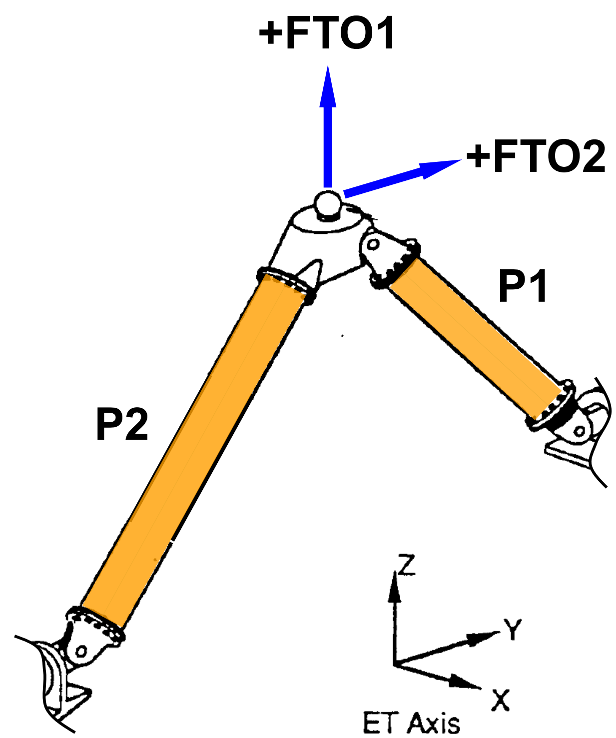
Limit values that provide rapid certification for FRR loads and DOL loads at max-Q condition

OV-ET Interface Loads, klbf

	Tension	Compr.
FTO1	+96.4	–127.8
FTO2	+64.5	–70.9

Bipod Strut Loads, klbf

	Tension	Compr.
P1	+74.3	–96.5
P2	+75.3	–97.4

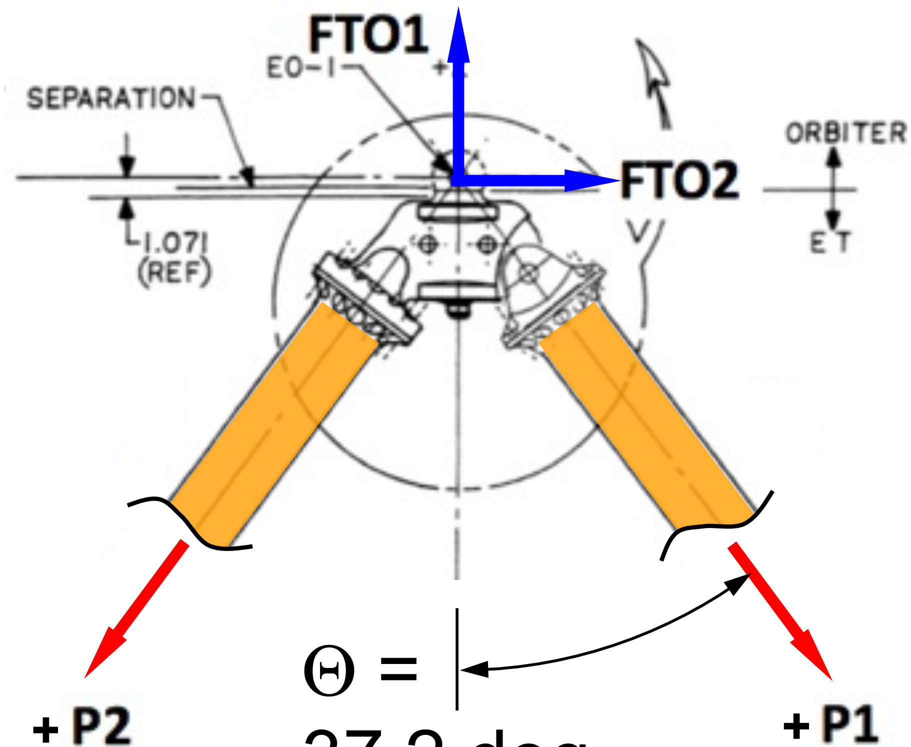


Ref.: Lockheed Martin Report 826-2470, May 2005

Forward Bipod Static Equilibrium

$$\Sigma F_Z: \text{FTO1} = \text{P1} \times \cos\Theta + \text{P2} \times \cos\Theta$$

$$\Sigma F_Y: \text{FTO2} + \text{P1} \times \sin\Theta = \text{P2} \times \sin\Theta$$

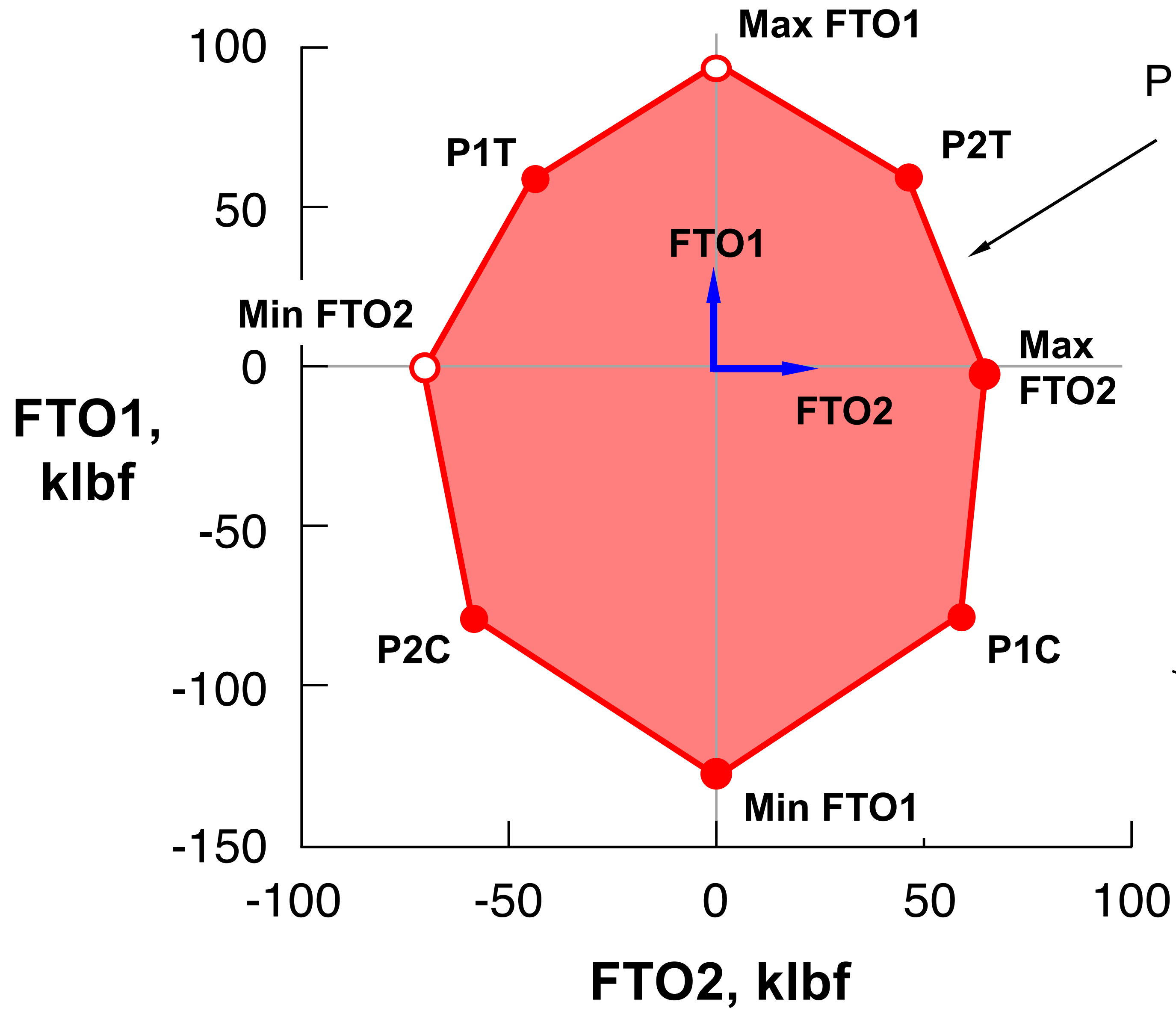


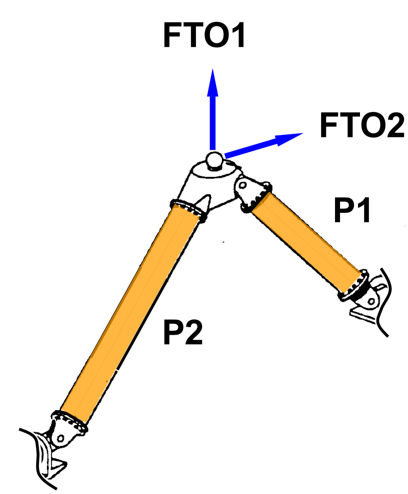
$$\begin{matrix}\text{FTO1}\\ \text{FTO2}\end{matrix} = \begin{bmatrix}\cos\Theta & \cos\Theta \\ -\sin\Theta & \sin\Theta\end{bmatrix} \begin{matrix}\text{P1}\\ \text{P2}\end{matrix}$$

$$\begin{matrix}\text{P1}\\ \text{P2}\end{matrix} = \begin{bmatrix}\sin\Theta & -\cos\Theta \\ \sin\Theta & \cos\Theta\end{bmatrix} \begin{matrix}\text{FTO1}\\ \text{FTO2}\end{matrix} \div (2 \times \sin\Theta \times \cos\Theta)$$

Ref.: Lockheed Martin SLWT
Syst. Def'n. Hdbk, Dec. 1997

Limit Envelope From Load Indicators





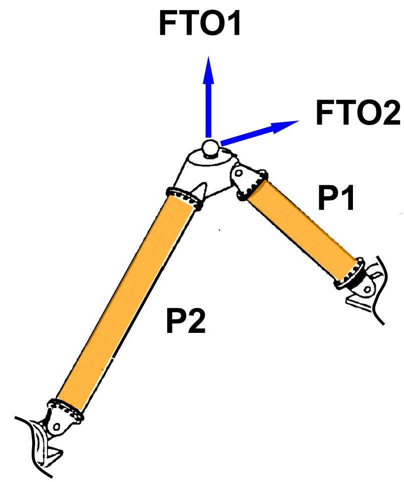
Ref.: Lockheed Martin Report 826-2470, May 2005

Forward Bipod Loads Tests

- Tests performed to validate Forward Bipod structural performance for ***six cases***:

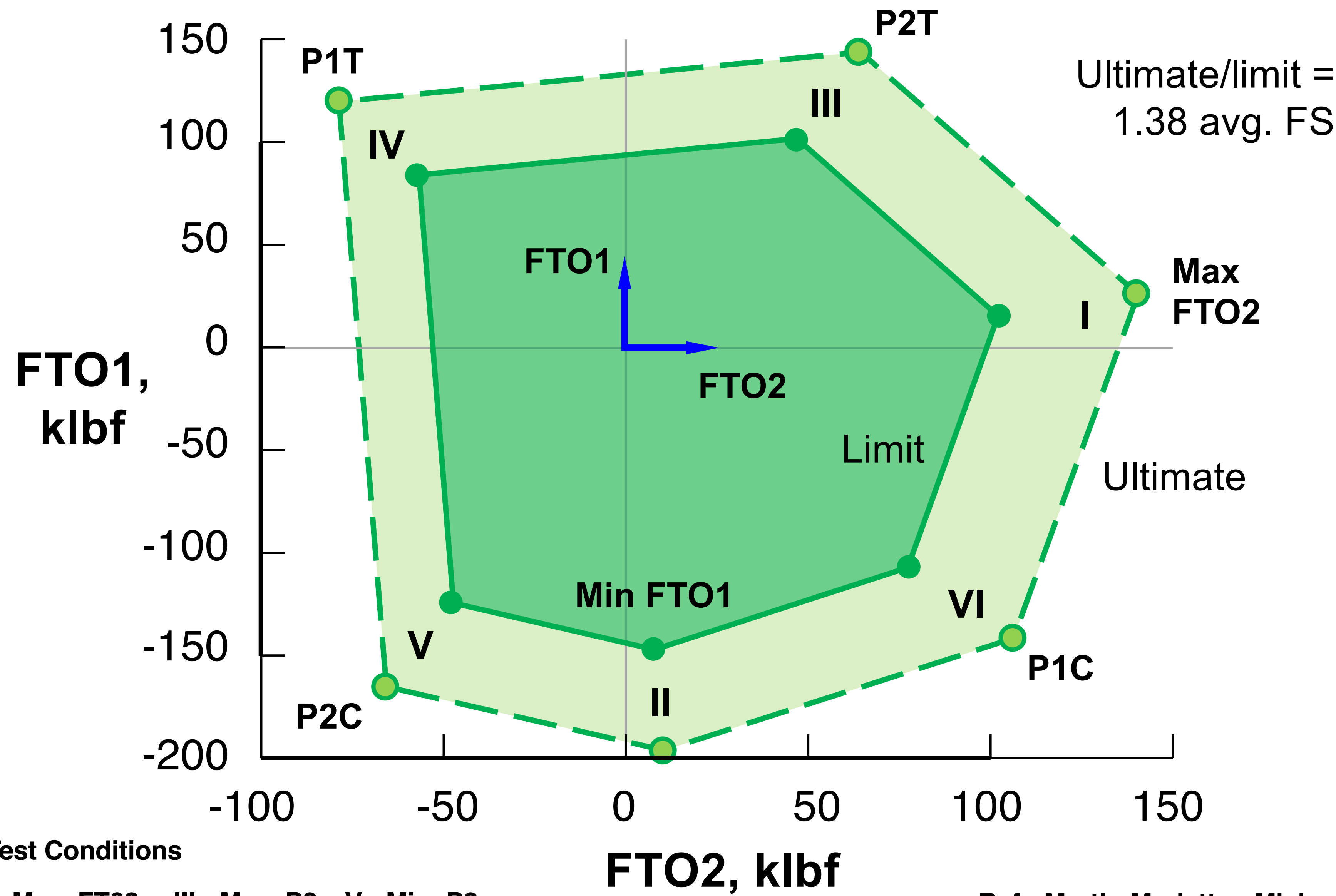
    I - Max FTO2, II - Min FTO1,
    III - Max P2T, IV - Min P1T,
    V - Min P2C, VI - Min P1C

- Tests performed to limit, ultimate, and selected failure load levels
- Max FTO1, Min FTO2 ***cases untested***
- P1 failure tests suggest significant additional capabilities past test ultimate loads, but how to apply results to P2, FTO1, FTO2?
- Air loads and moments applied in tests, but neglected in this analysis



Ref.: Martin Marietta - Michoud Report 826-2304, June 1985

Tested Limit And Ultimate Envelopes

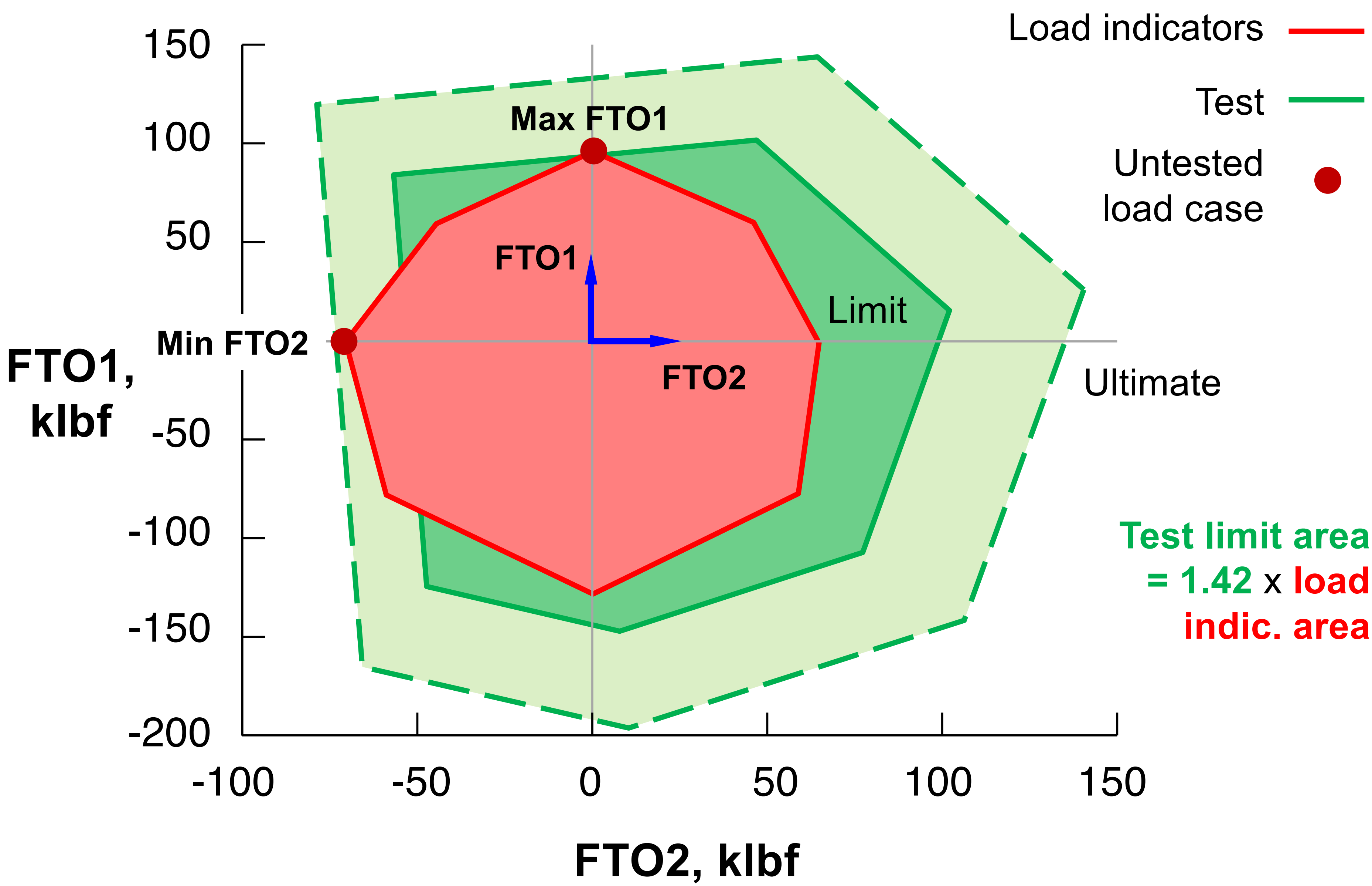


Test Conditions

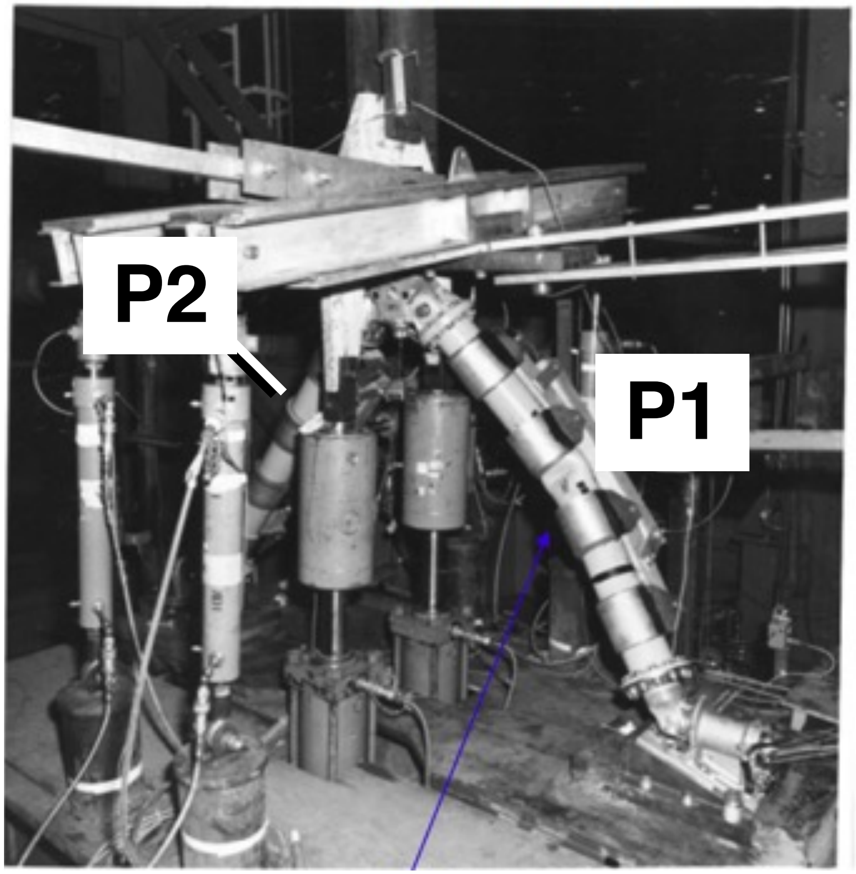
I - Max. FT02	III - Max. P2	V - Min. P2
II - Min. FT01	IV - Max. P1	VI - Min. P1

Ref.: Martin Marietta - Michoud Report 826-2304, June 1985

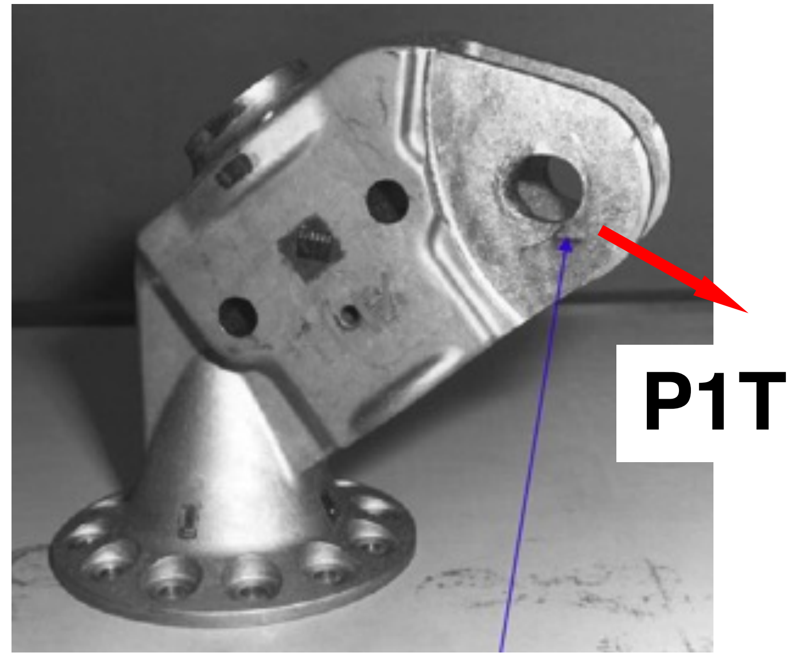
Comparison Of Loads Envelopes



P1 Strut Failure Tests Performed



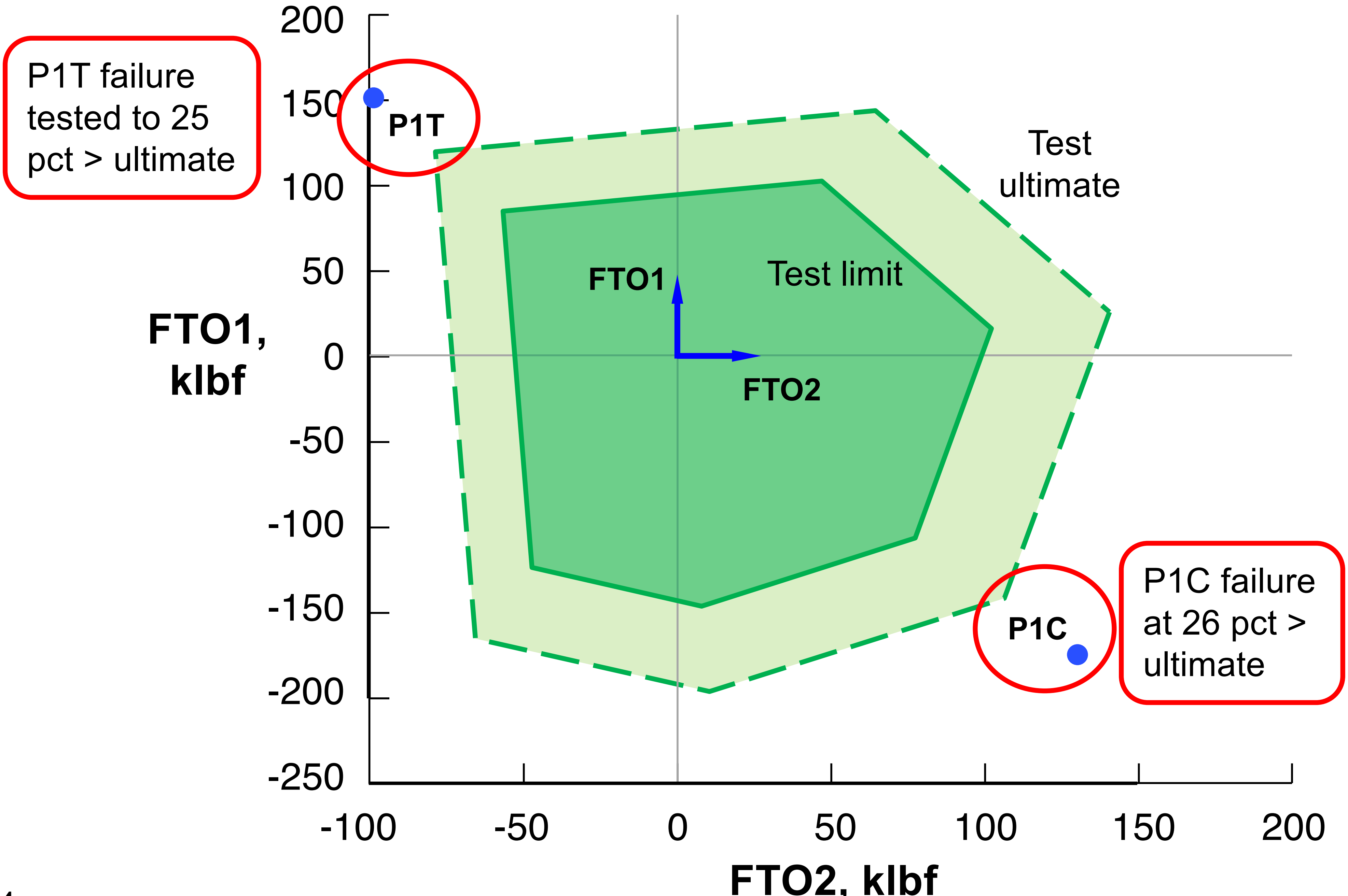
- P1 strut buckling at 126 percent of ultimate (P1C, case VI)



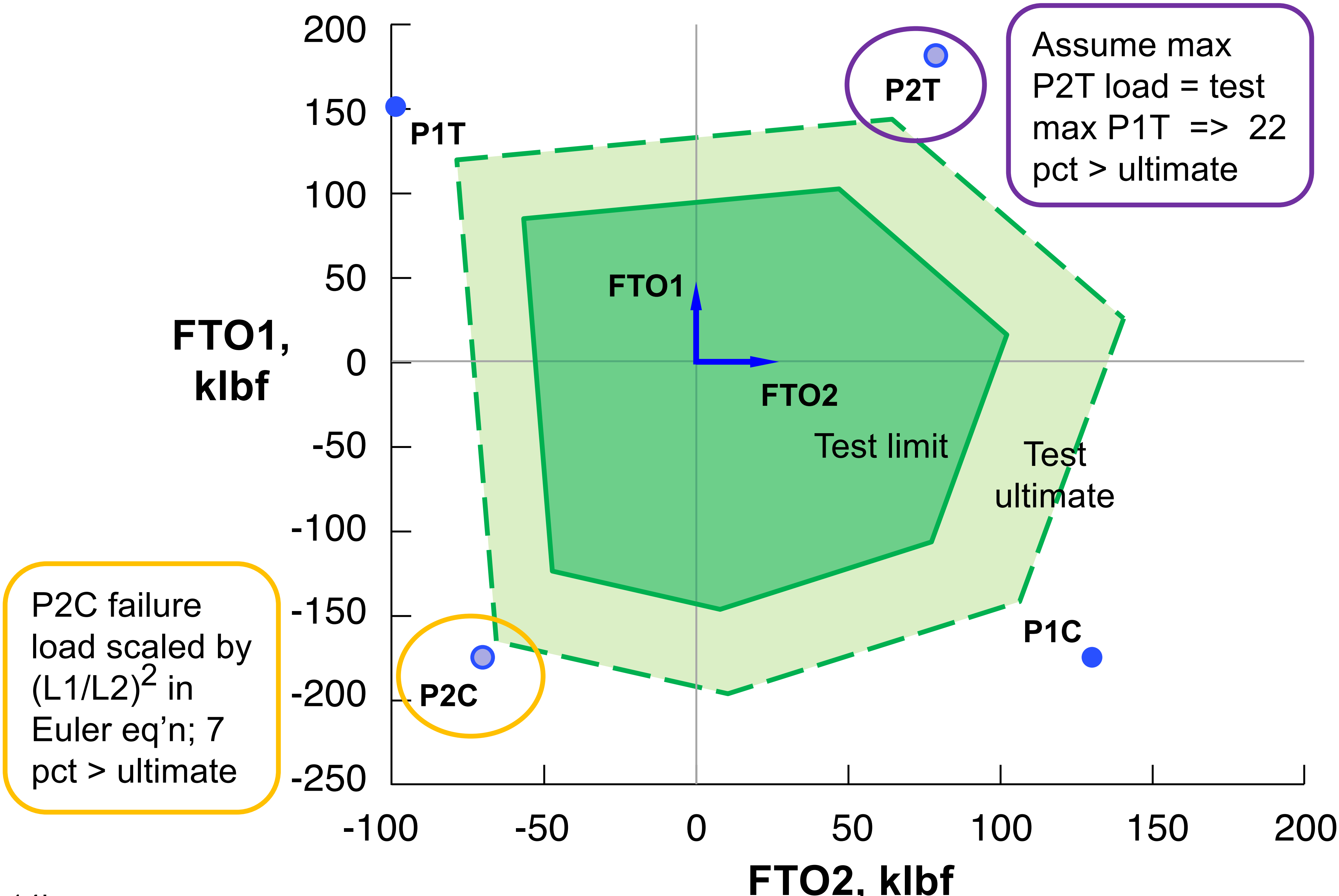
- P1 strut apex clevis tensile yield at 125 percent of ultimate (P1T, case IV)
- Conservative; *how much more load before joint fractures?*

Ref.: Martin Marietta - Michoud Report 826-2304, June 1985

Expand Loads Envelope Using Test Failures



Expand Loads Envelope Using Test Failures



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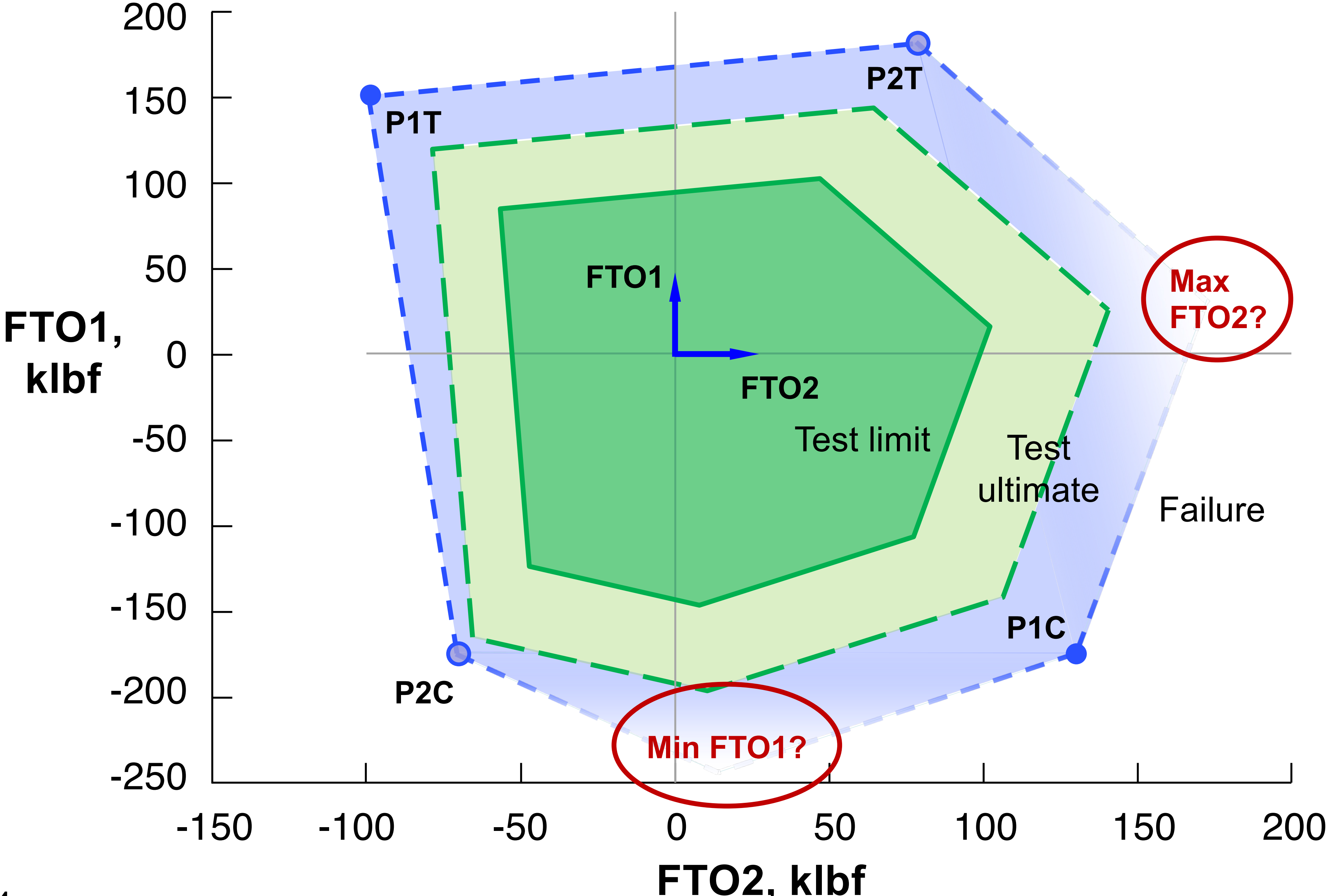

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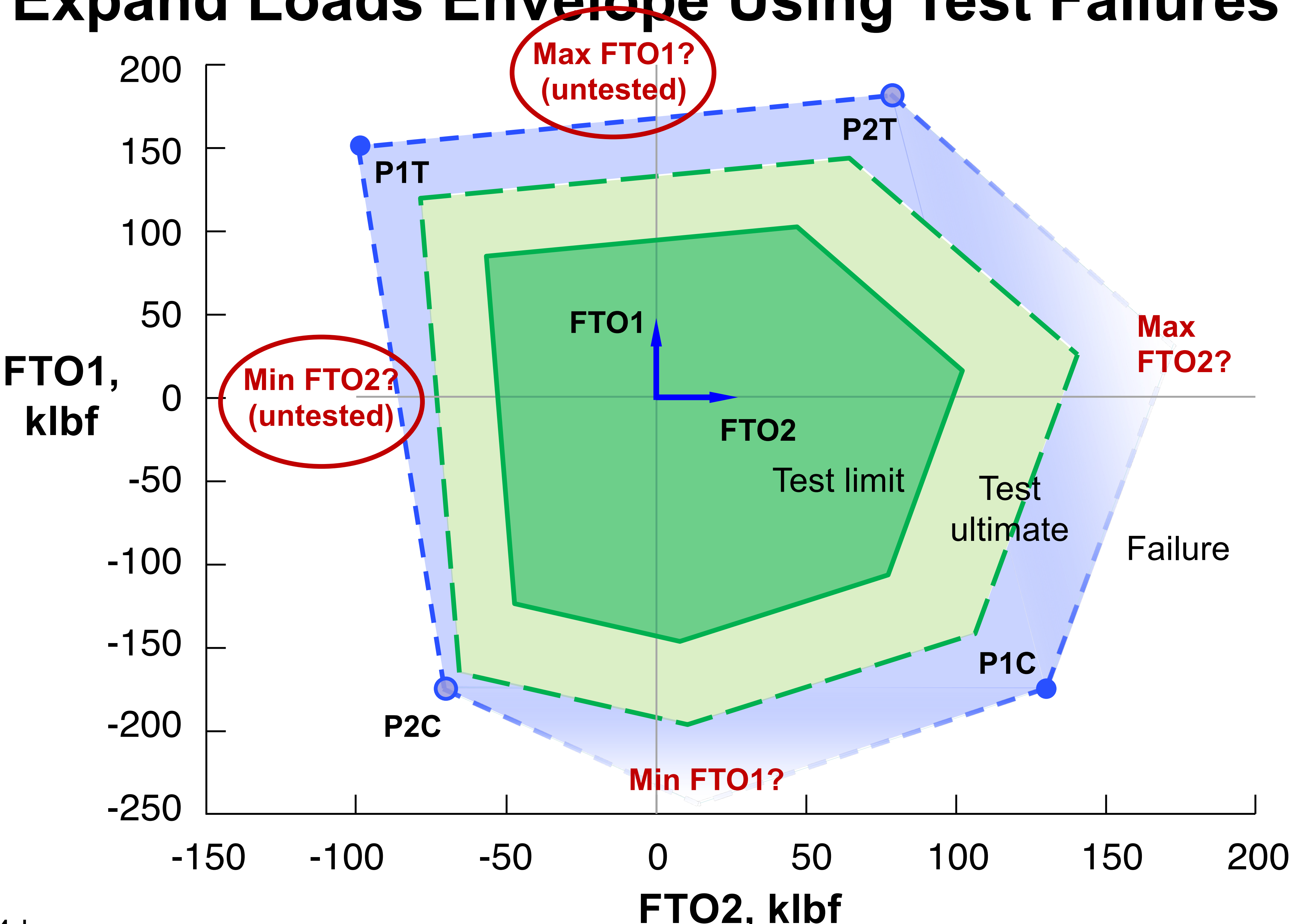
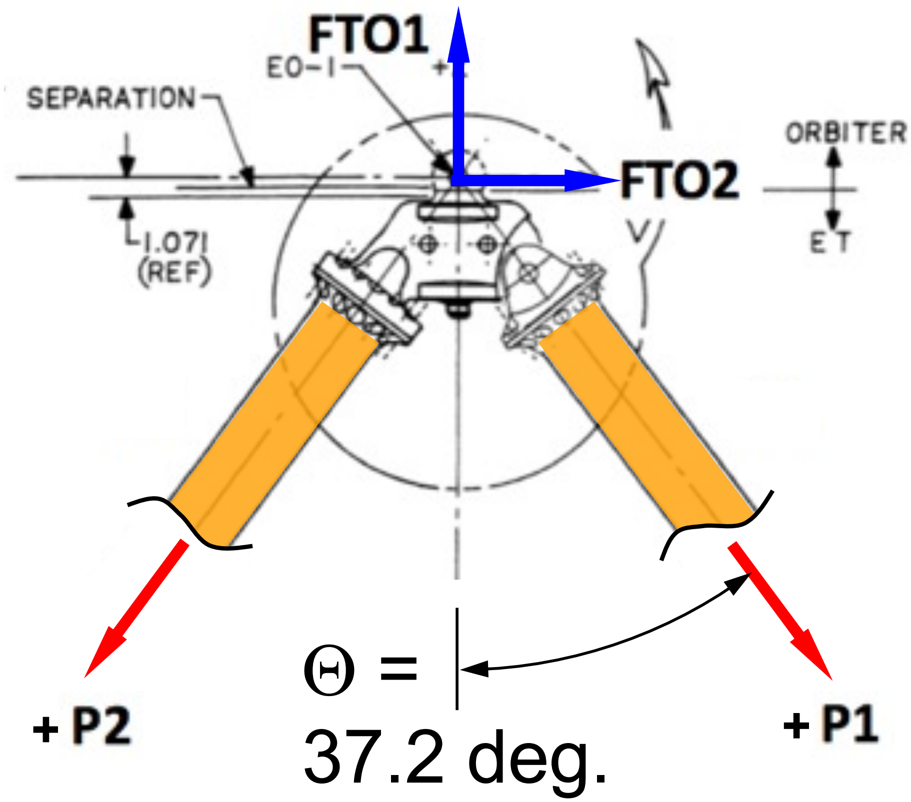


Forward Bipod Static Equilibrium (2)

$$\begin{matrix} FTO1 \\ FTO2 \end{matrix} = \begin{bmatrix} \cos\Theta & \cos\Theta \\ -\sin\Theta & \sin\Theta \end{bmatrix} \begin{matrix} P1 \\ P2 \end{matrix}$$

P1T, P2T => Max FTO1
P1C, P2C => Min FTO1

P1C, P2T => Max FTO2
P1T, P2C => Min FTO2



Tested:
P1T = +177.0 klbf
P1C = –220.9 klbf

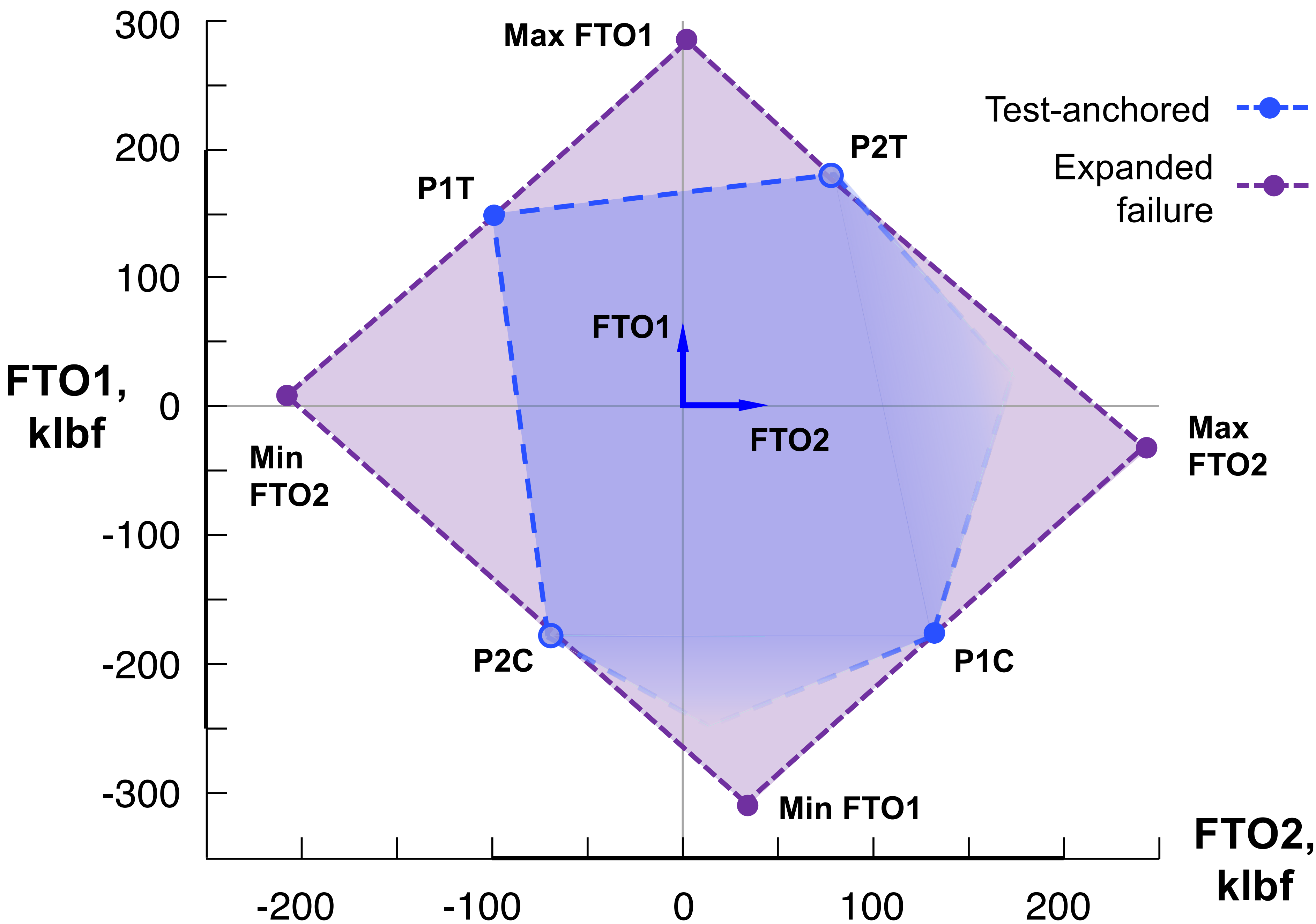
Assumed:
P2T = +177.0 klbf
P2C = –168.8 klbf

Ref.: Lockheed Martin SLWT Syst. Def'n. Hdbk, Dec. 1997

Add'l Analyses To Expand Failure Envelope

- Compute Max FTO2, Min FTO1 loads using strut failure loads and Bipod geometry
- Apply measured P1 failure loads, and predicted P2 failure loads
    + Max FTO2 = +241 klbf
        * 74 percent > test ultimate
    + Min FTO1 = –311 klbf
        * 59 percent > test ultimate
- Compute ***untested*** Max FTO1, Min FTO2 load cases using P1 and P2 failure loads
    + Max FTO1 = +282 klbf
    + Min FTO2 = –209 klbf

Expanded Failure Envelope



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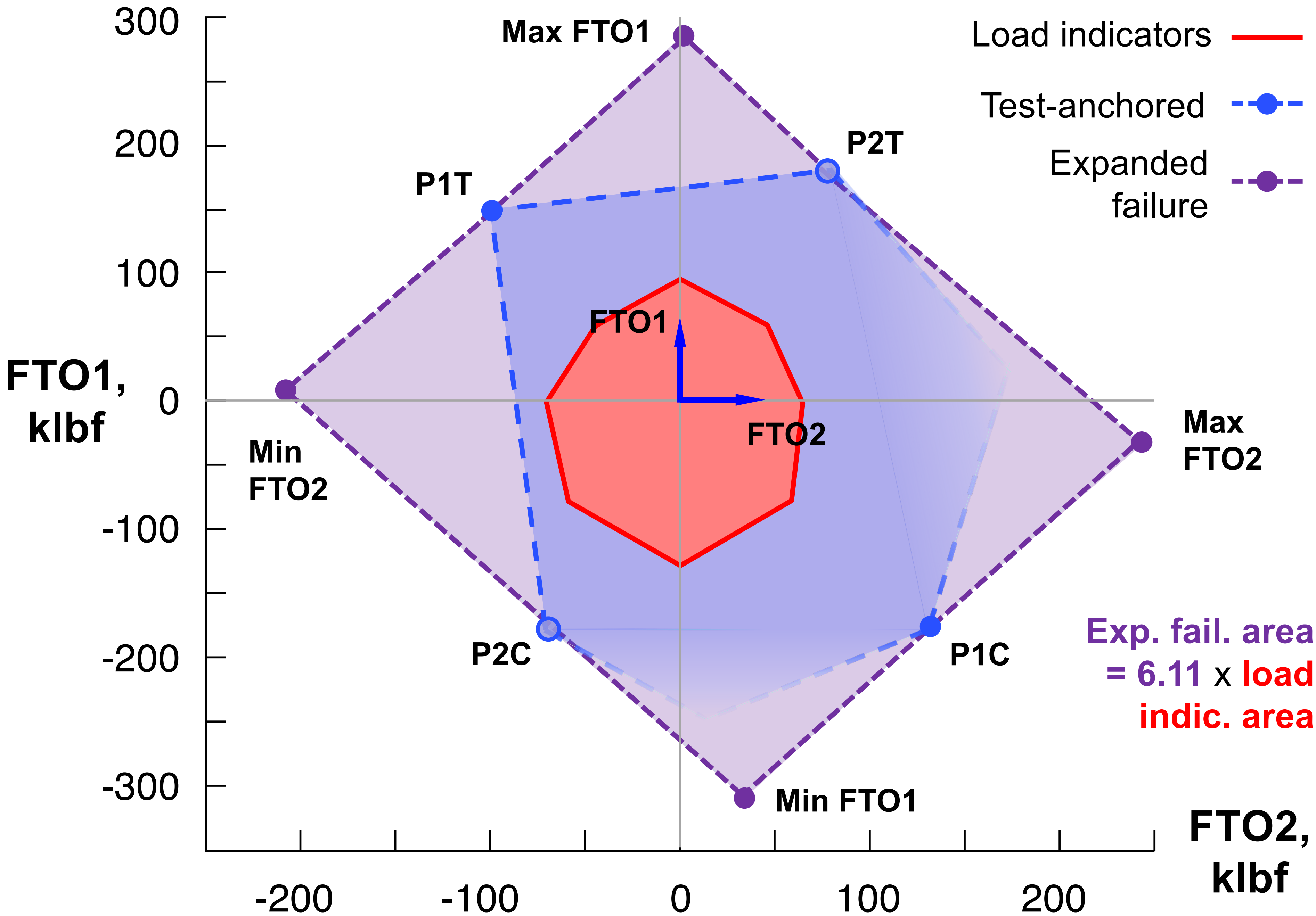
Expanded Failure Envelope (2)



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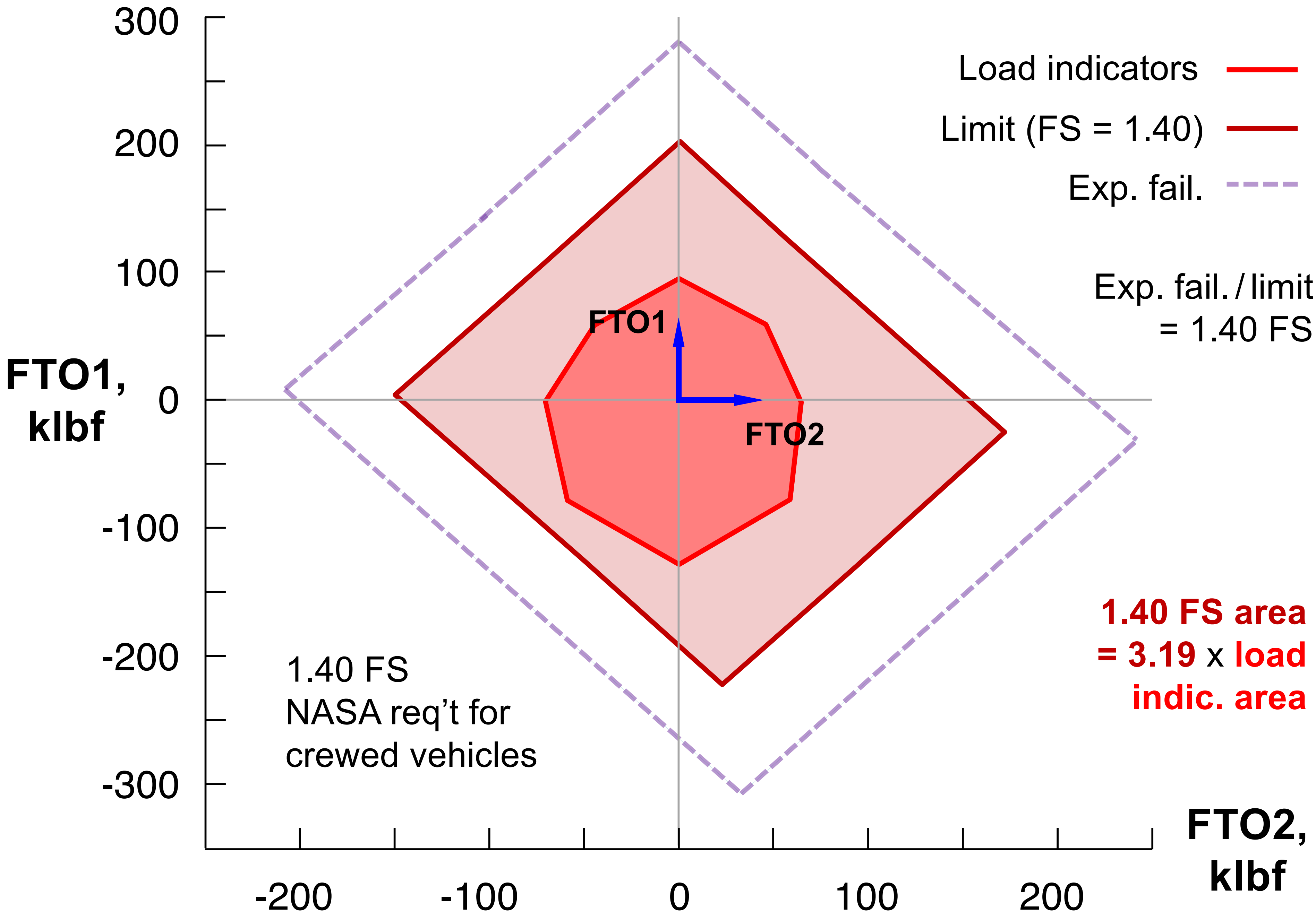
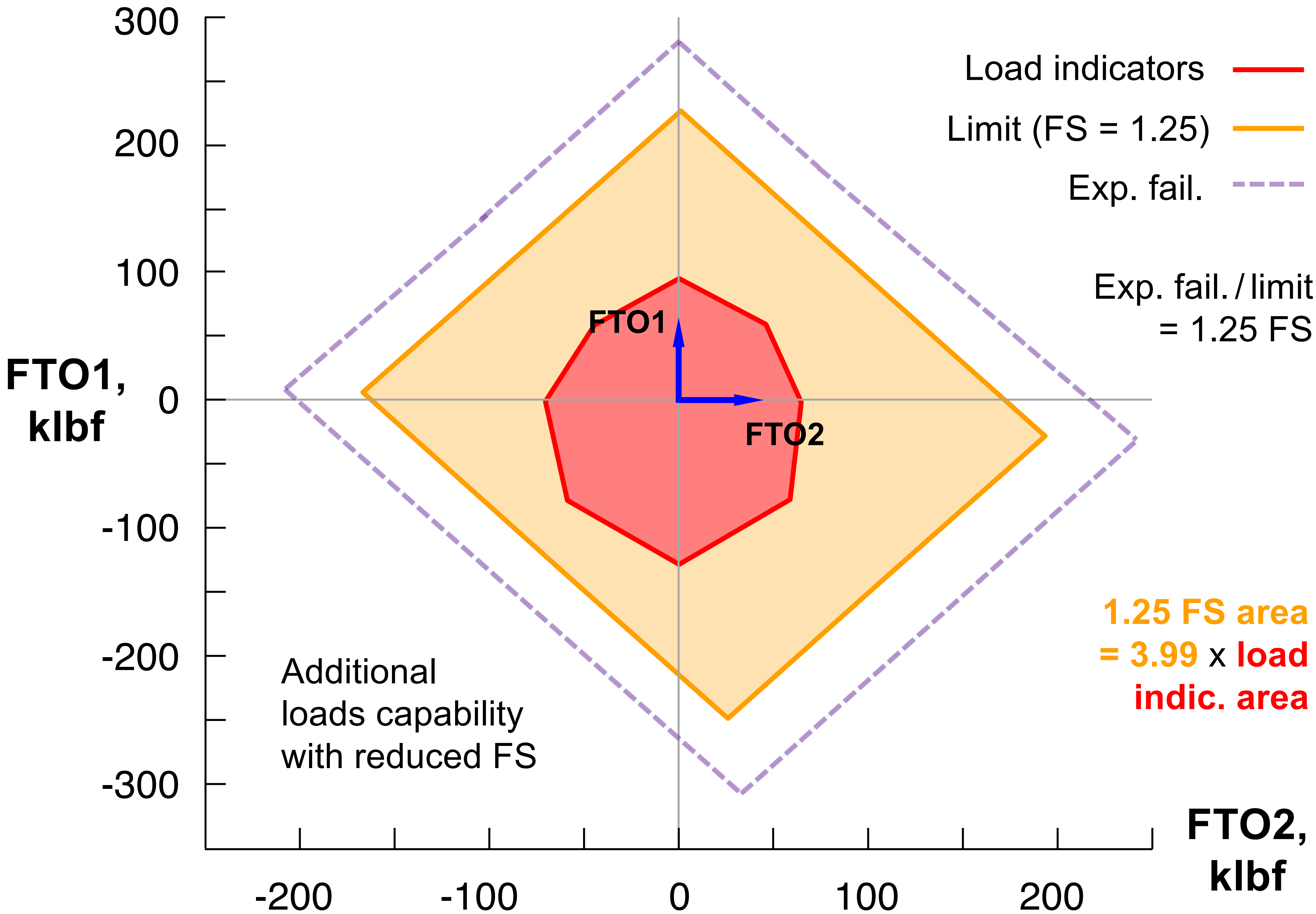
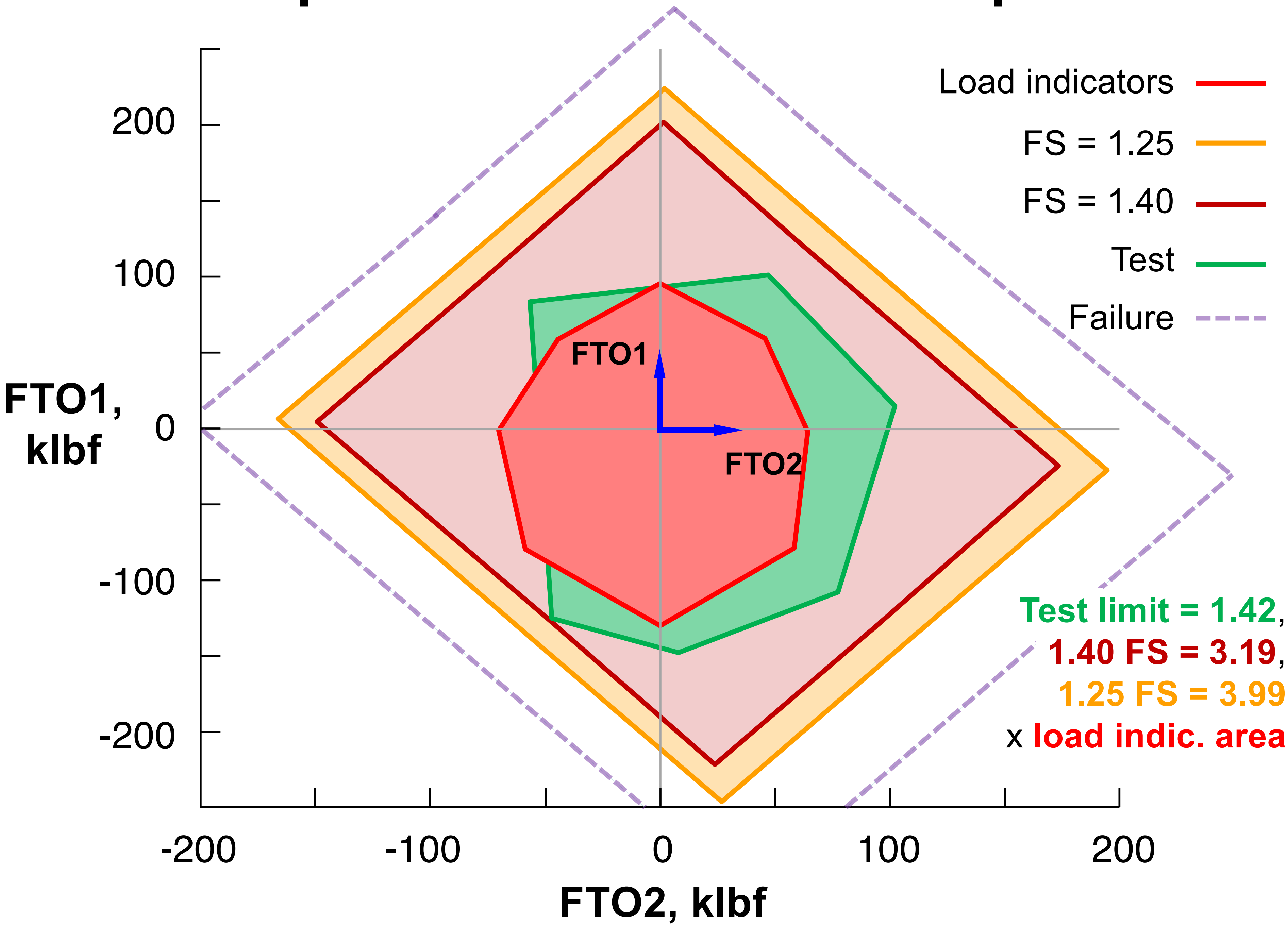
Define New Limit Envelope, FS = 1.40



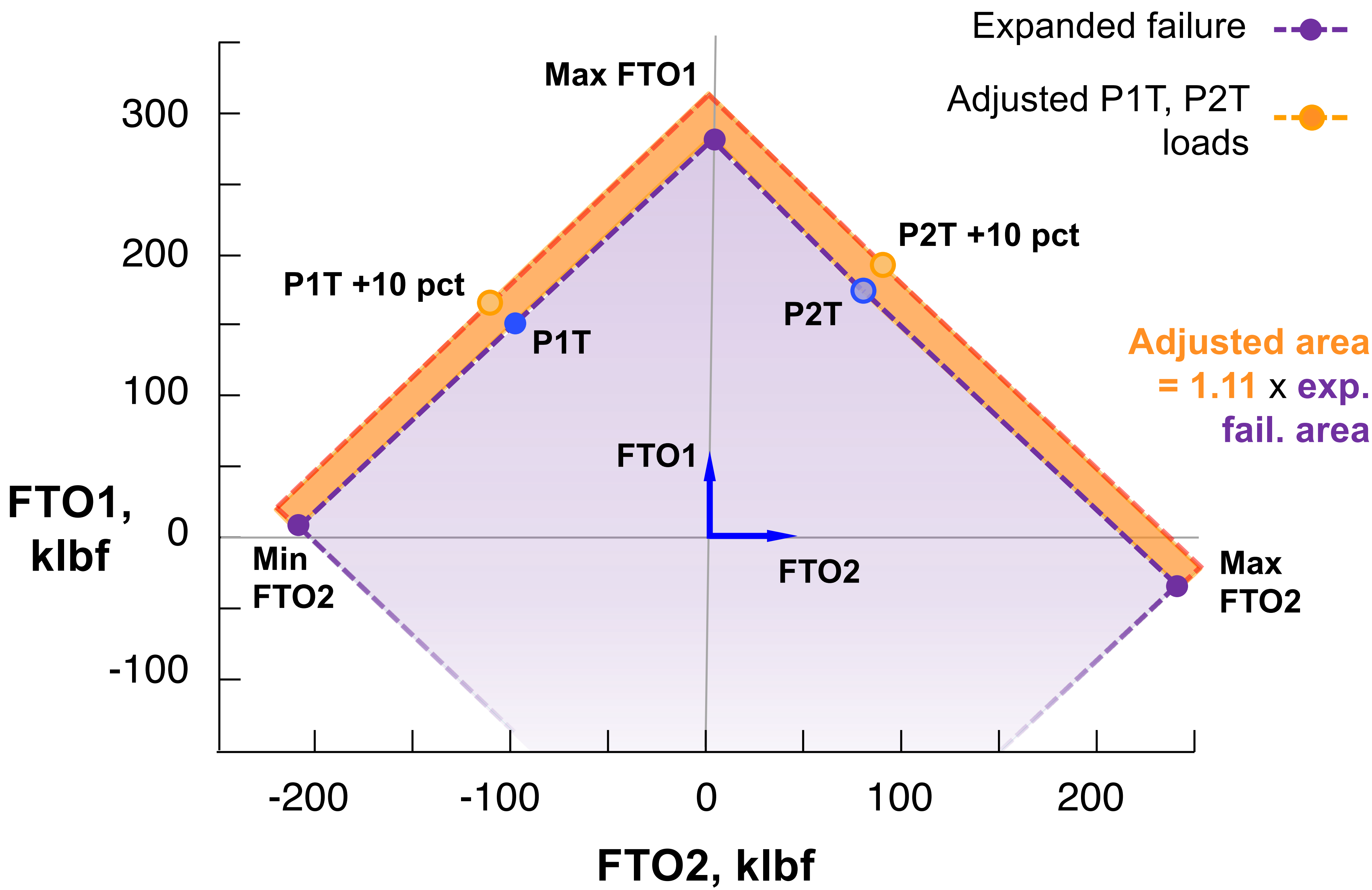
Define New Limit Envelope, FS = 1.25



Comparison Of Limit Envelopes



Assess Sensitivity To P1T, P2T Failure Loads



Concluding Remarks

- Load indicators used during Shuttle Program to certify Bipod operational performance
- Tests performed to limit, ultimate, and selected failure load levels
- Results of P1 failure tests indicate significant conservatism in Bipod design
- P1, P2 strut failure loads applied to define an expanded, test-anchored failure envelope
- Expanded limit envelopes defined using standard 1.40 and reduced 1.25 Factors of Safety

Forward Bipod can support significant loads beyond those applied during Shuttle ascent

NASA Kennedy Space Center - April 2010

Space Shuttle Atlantis - STS-132

Space Shuttle Atlantis - STS-132