# Built-in-place Refuge Alternative Door Blast Analysis and Design Modifications


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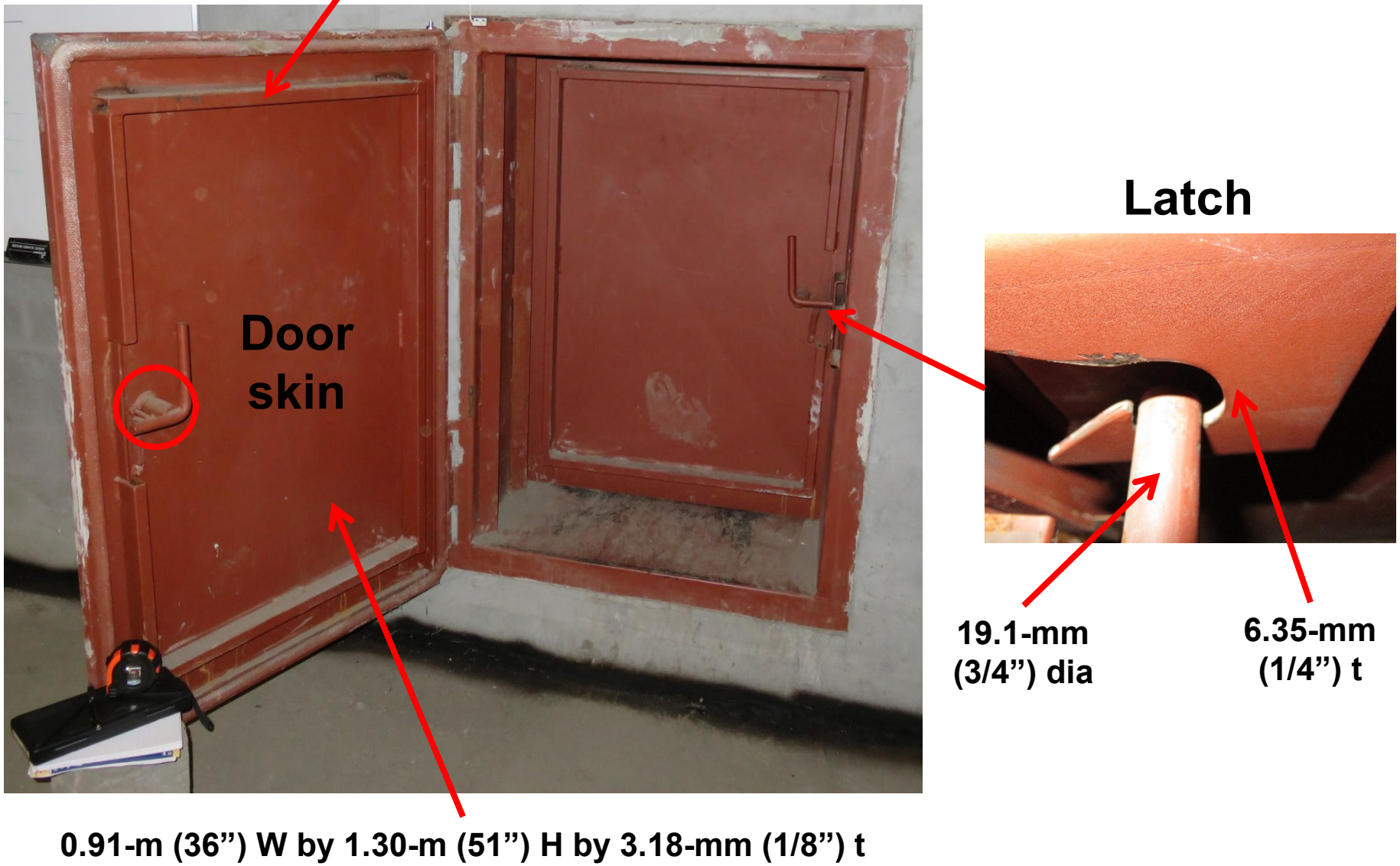
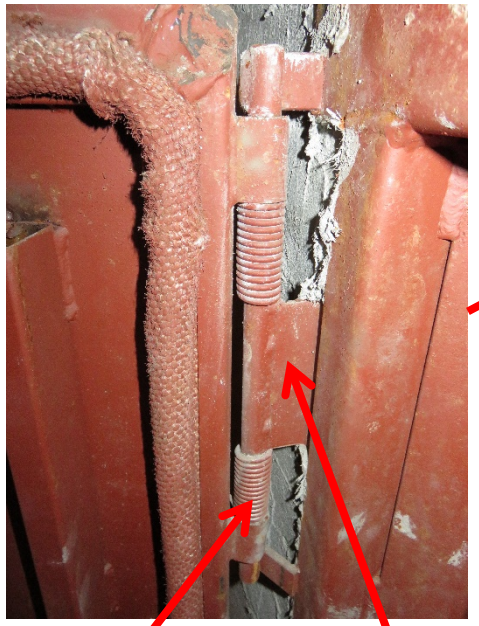


# NIOSH used finite element (FE) analysis to examine the blast response of a door for a coal mine built-in-place refuge alternative.

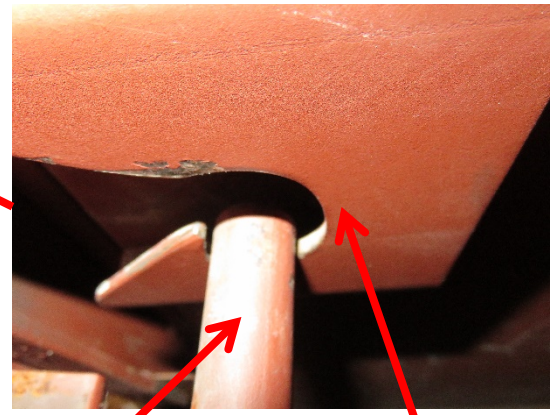

Hinge



1.59-mm (5/8”)

3.18-mm (1/8”) t

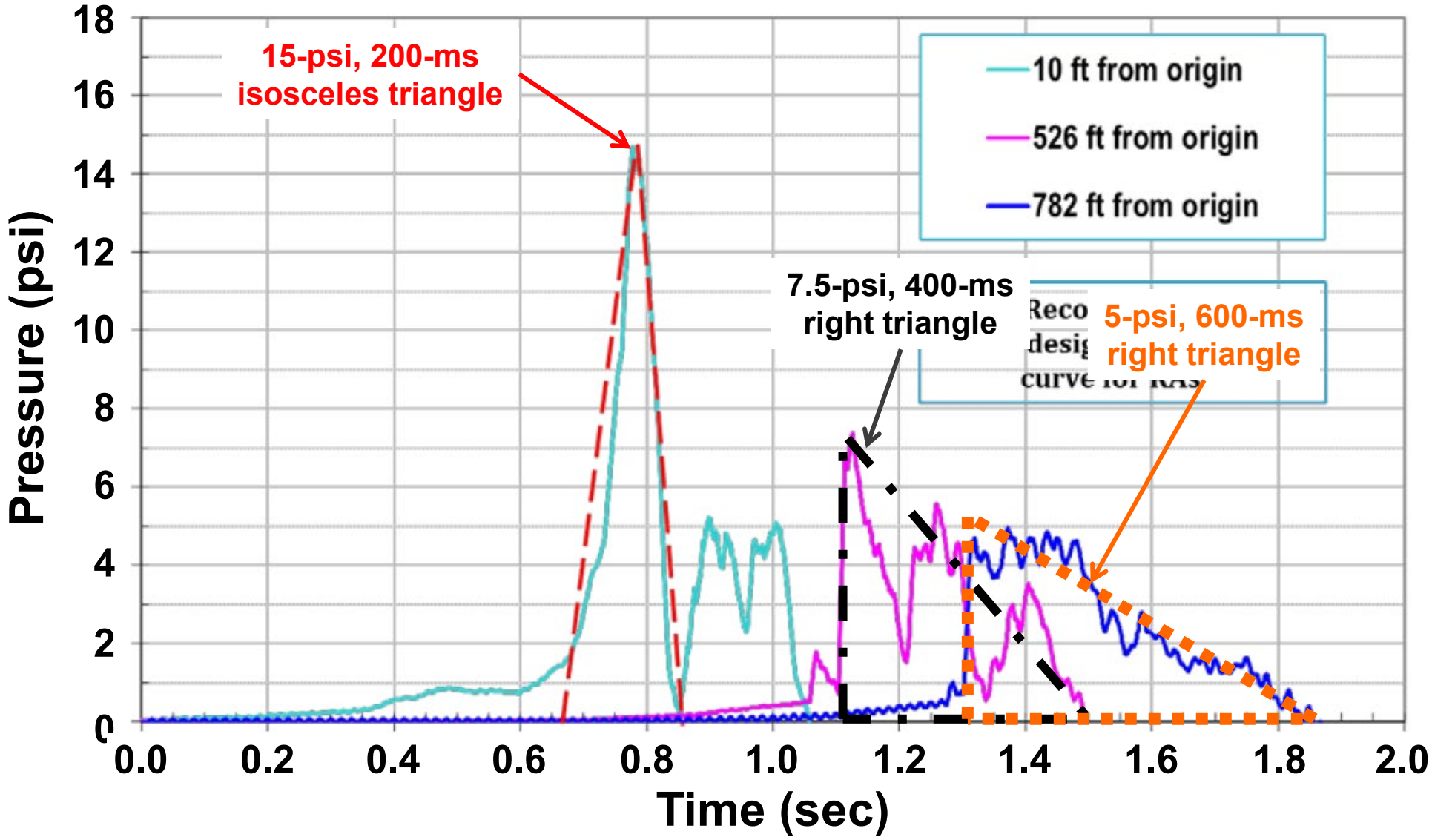
Latch



19.1-mm (3/4”) dia

6.35-mm (1/4”) t

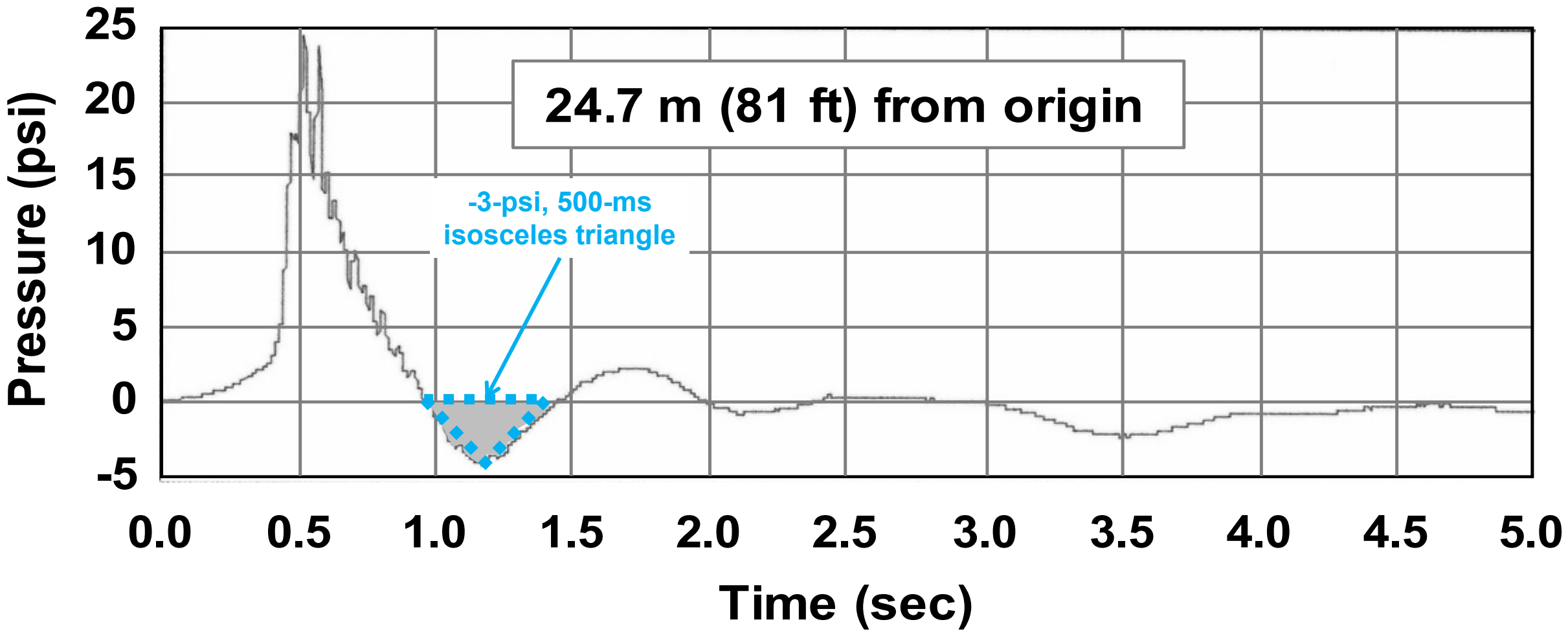
# The analysis considered the idealized blast waveform from federal RA regulations and other blast pressures from Lake Lynn Laboratory test data.




*From RI 9698: Facilitating the Use of Built-in-place Refuge Alternatives in Mines*

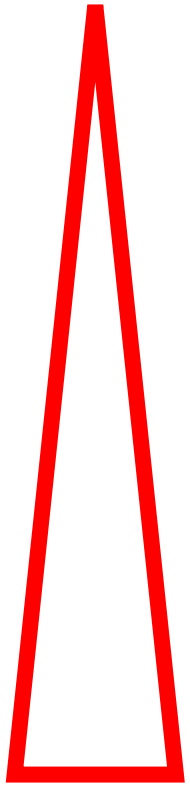
# The analysis also considered blast waveforms from Lake Lynn Laboratory test data that exhibited negative pressure.

***Negative pressures applied to a BIP RA door must be restrained by the hinges and latching mechanism!***

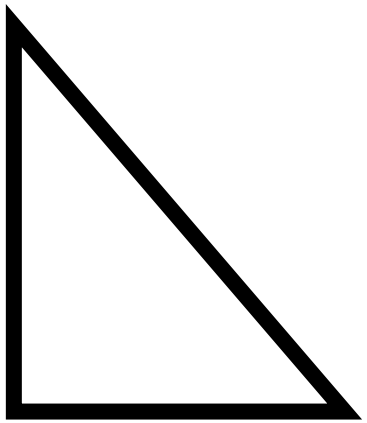



*From Lake Lynn Laboratory Test 420 in A Drift, 10/31/2002*

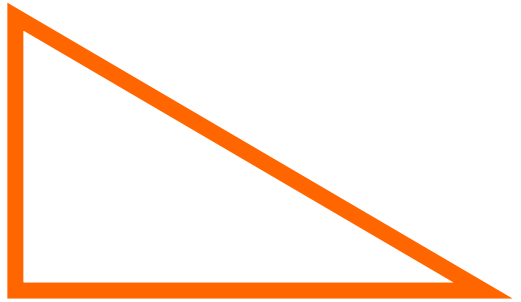
# We used three positive-pressure and one negative-pressure idealized blast waveforms in the analysis.



15-psi, 200-ms
isosceles triangle

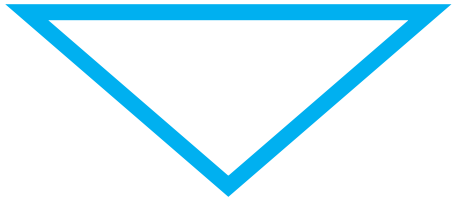


7.5-psi, 400-ms
right triangle

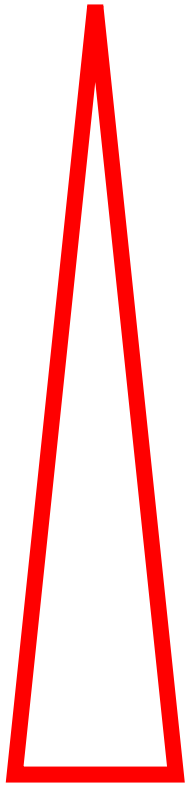


5-psi, 600-ms
right triangle

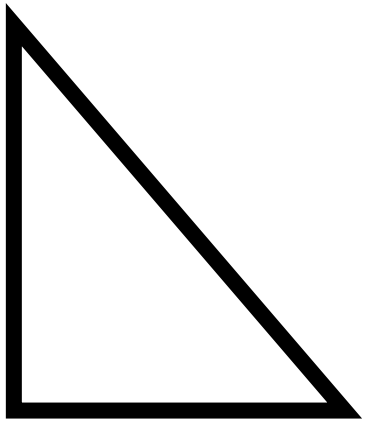
-3-psi, 500-ms
isosceles triangle



# We used three positive-pressure and one negative-pressure idealized blast waveforms in the analysis.

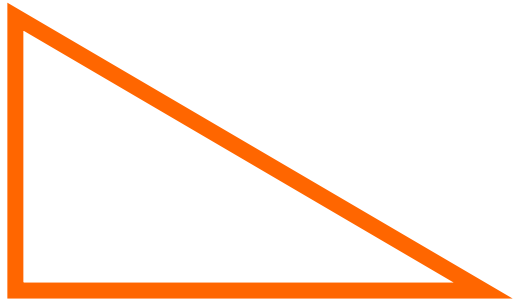


**15-psi, 200-ms isosceles triangle**

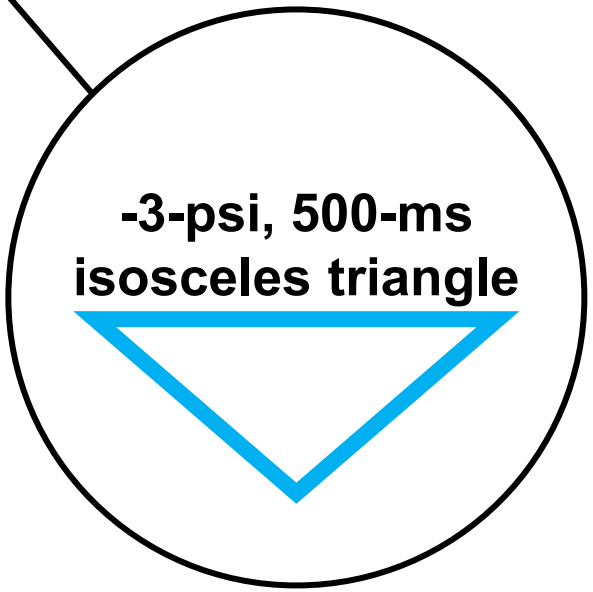


**7.5-psi, 400-ms right triangle**

*Note: In the calculation of the effects of the negative pressure, we are ignoring energy stored in the door due to the positive pressure load (rebound load).*

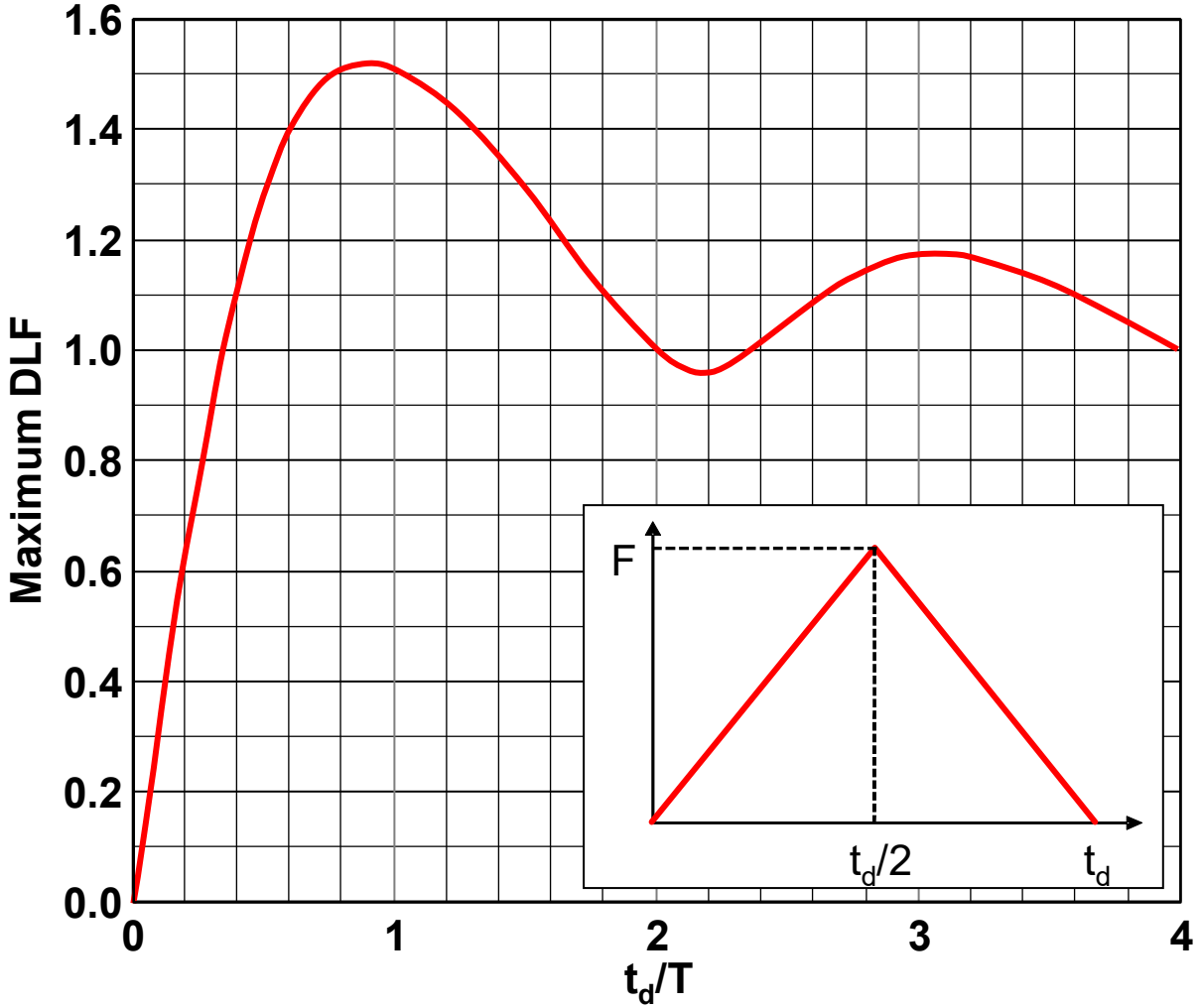


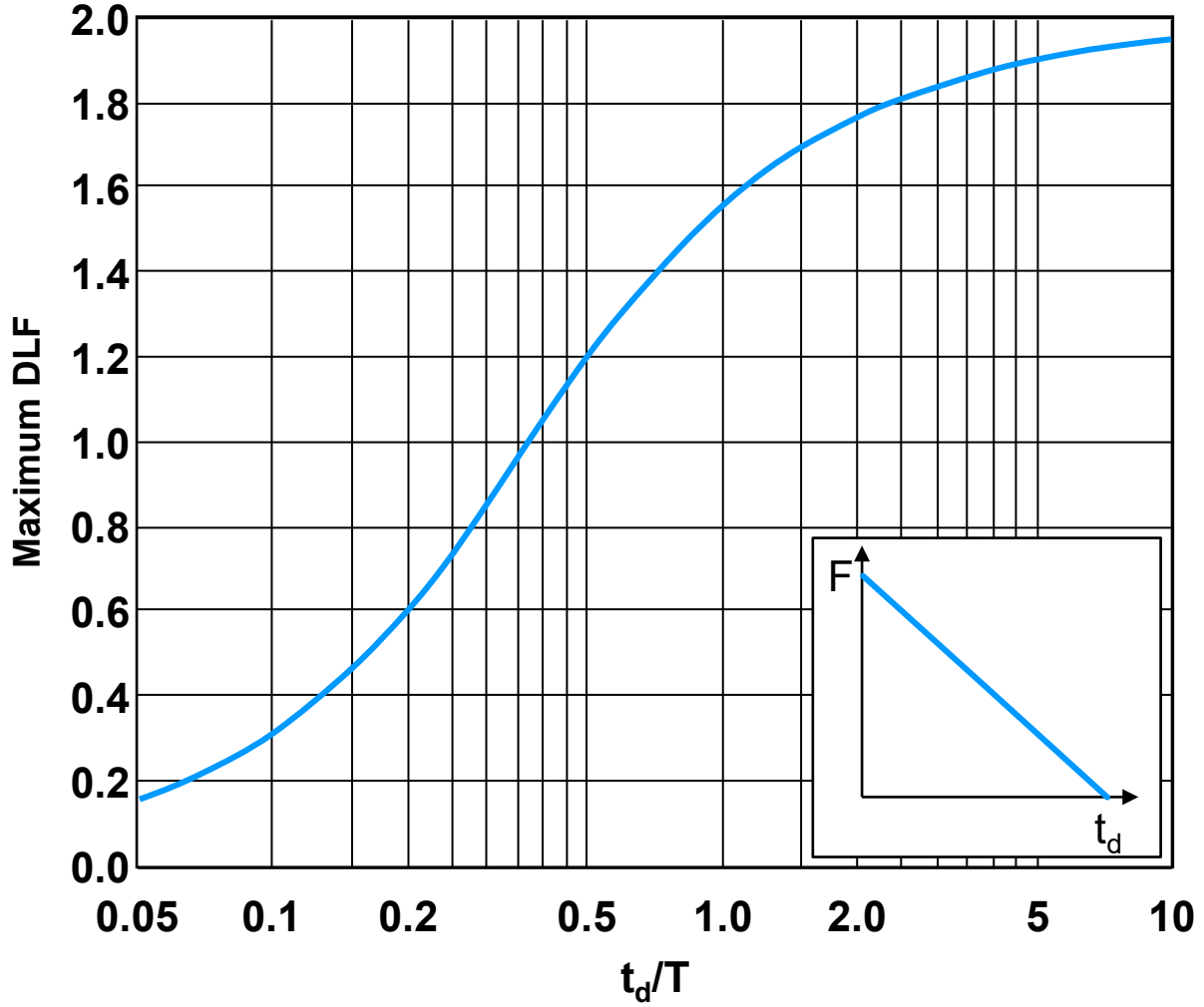
**5-psi, 600-ms right triangle**



# We used the “dynamic load factor” so that a linear static FE analysis could be used to estimate the door blast response.

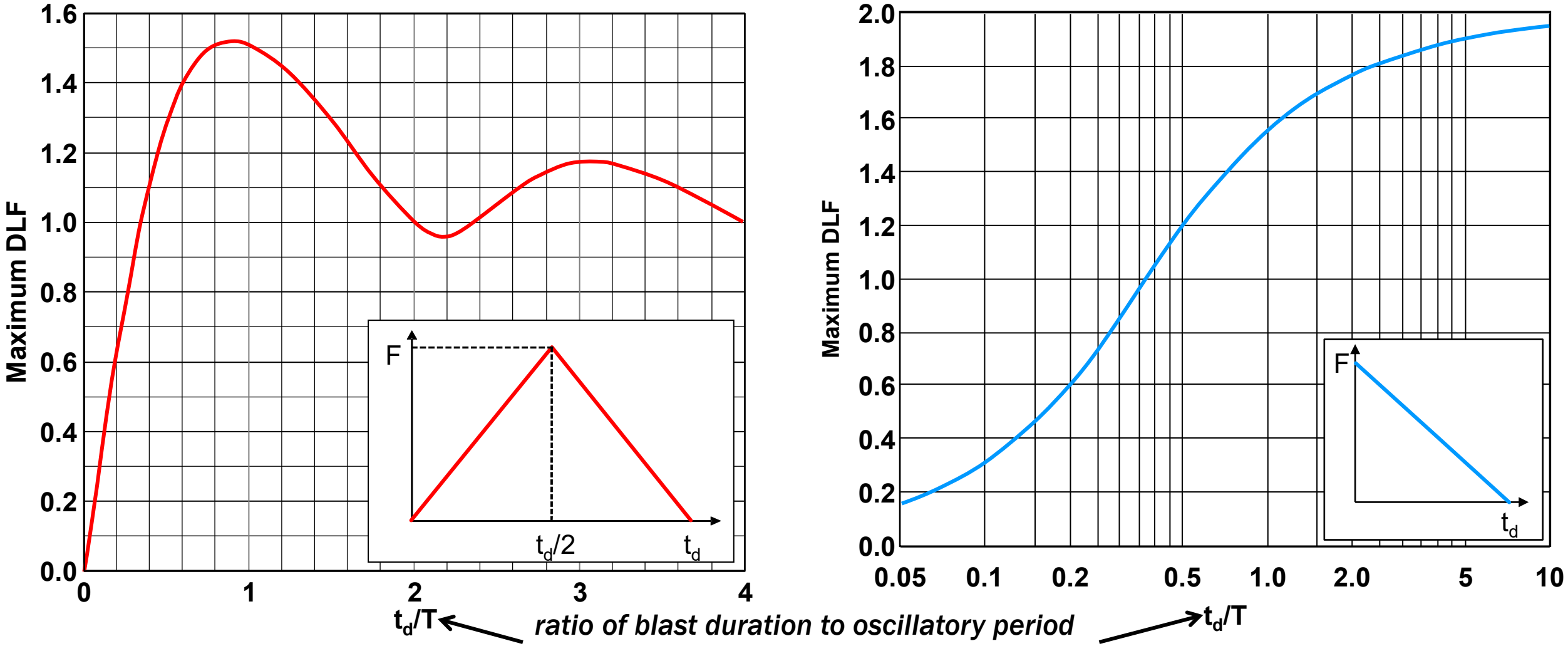
*Note: Linear static FE analysis can only predict if yielding will occur, it cannot predict the actual stress or deflections beyond yield.*




*Biggs, J.M. (1964). Introduction to Structural Dynamics. New York, NY: McGraw-Hill Book Company.*

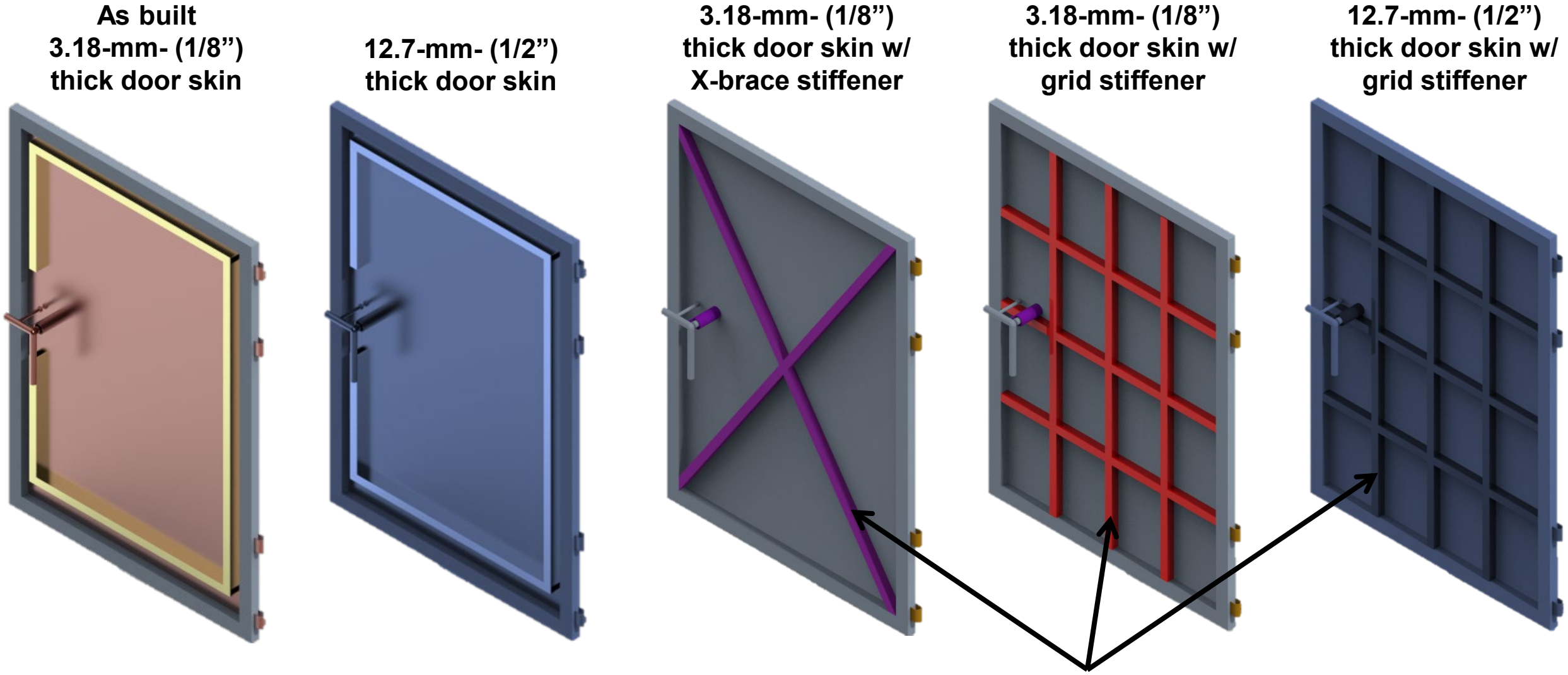
# We calculated the maximum DLF was using the characteristics of each idealized blast waveform and the door's fundamental natural frequency.



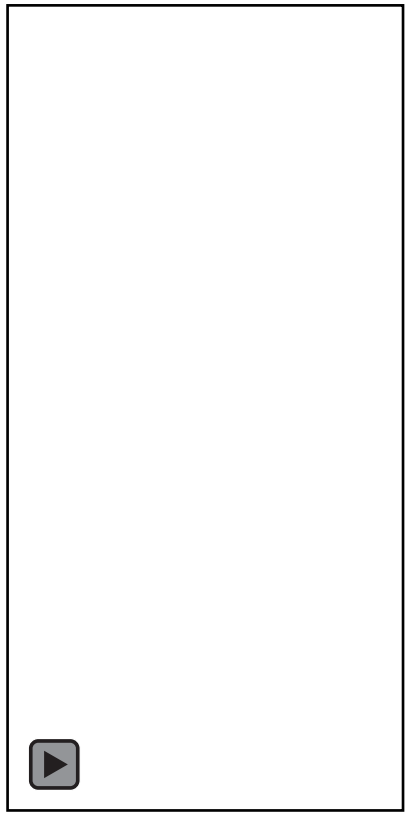
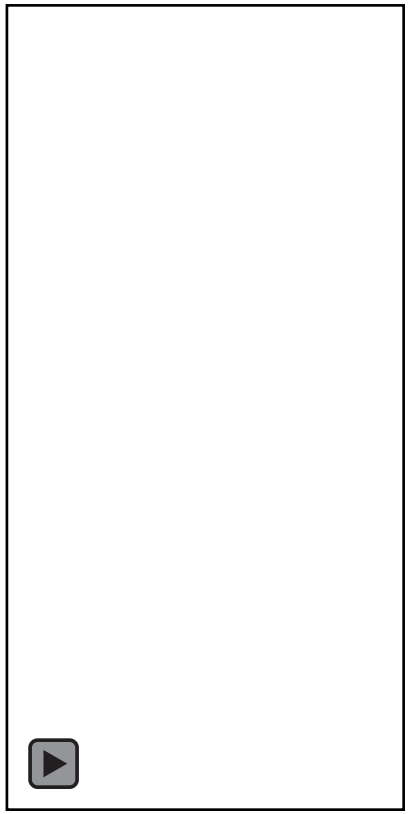
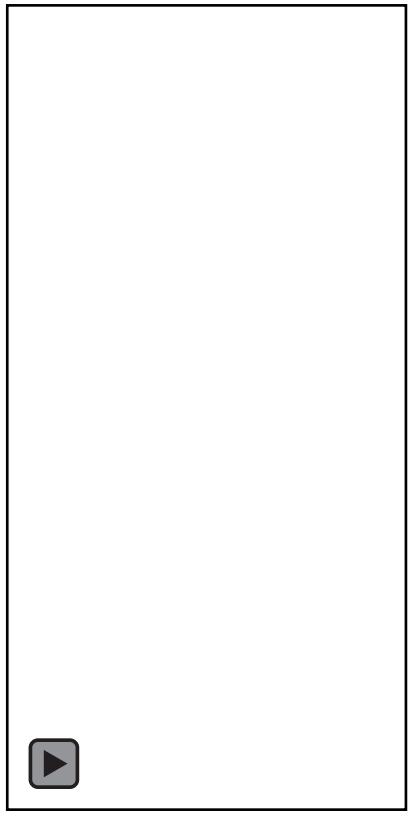
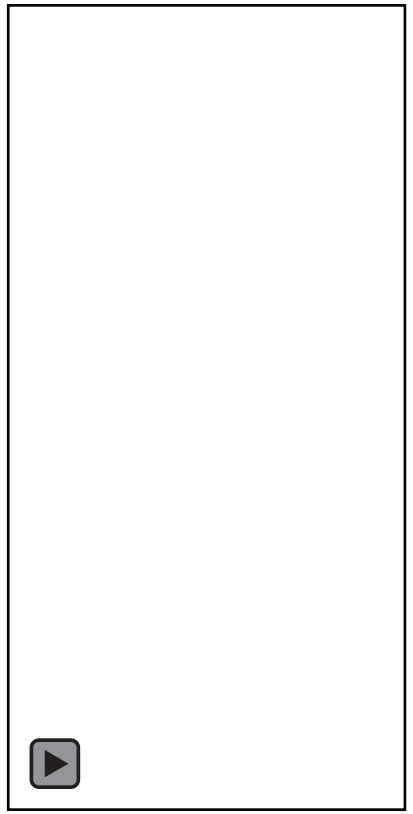
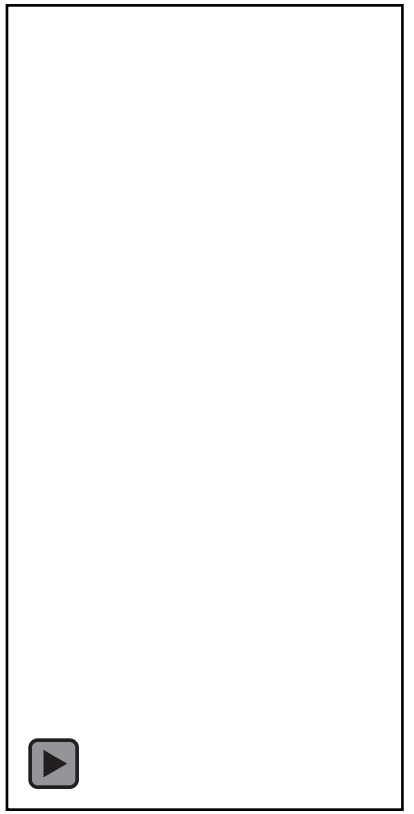

***ratio of blast duration to oscillatory period for door's 1st natural frequency***

*Biggs, J.M. (1964). Introduction to Structural Dynamics. New York, NY: McGraw-Hill Book Company.*

# We used FE analysis to predict if yielding would occur for the “as built” door and several modified door designs.

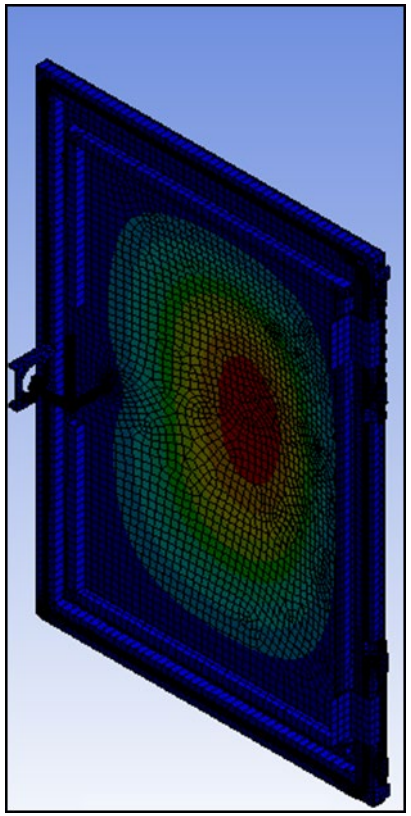


# FE analysis was used to determine the first natural frequency for each door. Then, we calculated the ratio of the blast duration to the door's first natural period for each load.

| As built 3.18-mm- (1/8") thick door skin | 12.7-mm- (1/2") thick door skin | 3.18-mm- (1/8") thick door skin w/ X-brace stiffener | 3.18-mm- (1/8") thick door skin w/ grid stiffener | 12.7-mm- (1/2") thick door skin w/ grid stiffener |
|---|---|---|---|---|
|  |  |  |  |  |
| F = 40.8 Hz<br>T = 0.0245 sec | F = 74.1 Hz<br>T = 0.0135 sec | F = 68.1 Hz<br>T = 0.0147 sec | F = 102.9 Hz<br>T = 0.00972 sec | F = 88.3 Hz<br>T = 0.0113 sec |

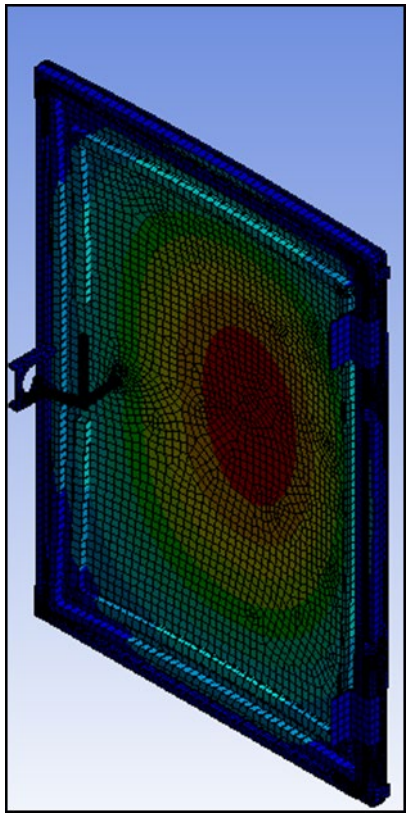
# For the *15-psi, 200 ms isosceles-triangle-shaped blast load*, $t_d/T$ ranged from 8.2 to 20.5 for the different door designs.

**As built 3.18-mm- (1/8”) thick door skin**



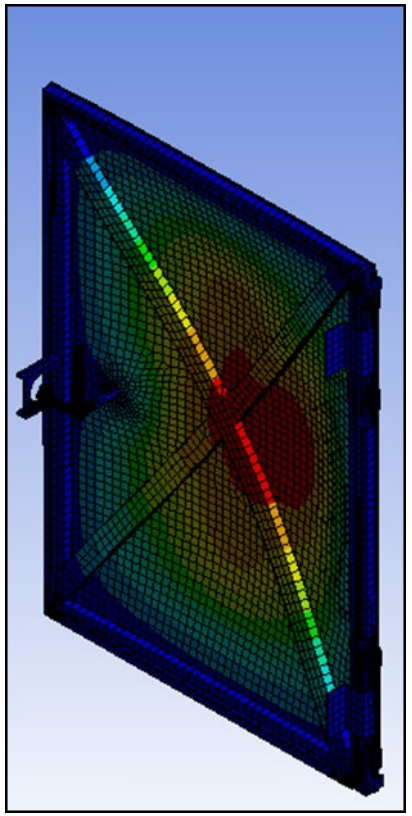
**T = 0.0245 sec**
**$t_d/T$ = 8.2**

**12.7-mm- (1/2”) thick door skin**



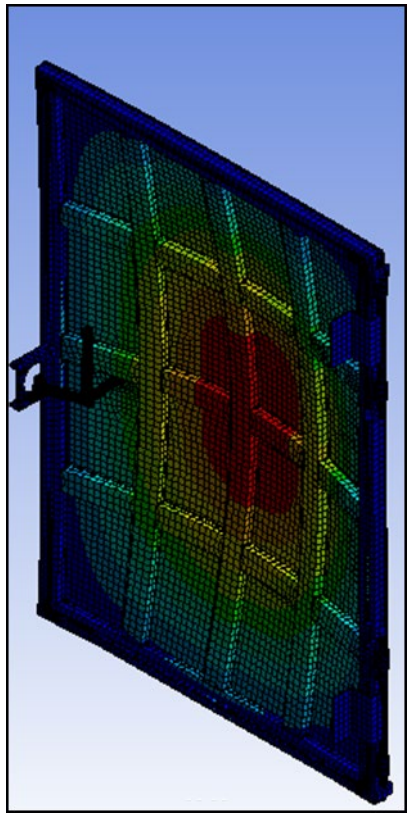
**T = 0.0135 sec**
**$t_d/T$ = 14.8**

**3.18-mm- (1/8”) thick door skin w/ X-brace stiffener**



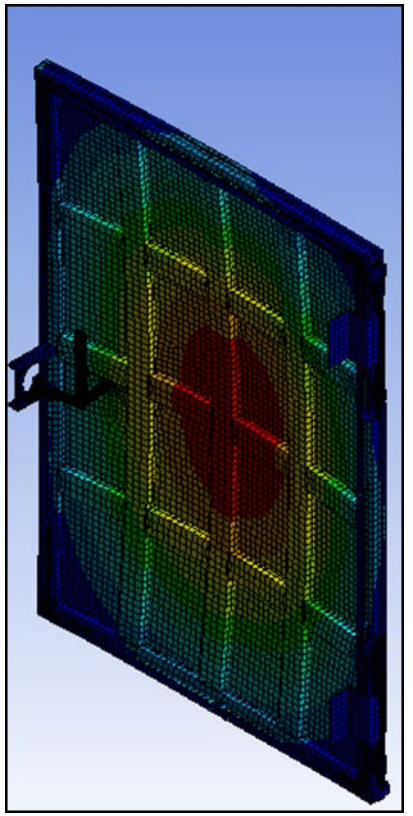
**T = 0.0147 sec**
**$t_d/T$ = 13.6**

**3.18-mm- (1/8”) thick door skin w/ grid stiffener**



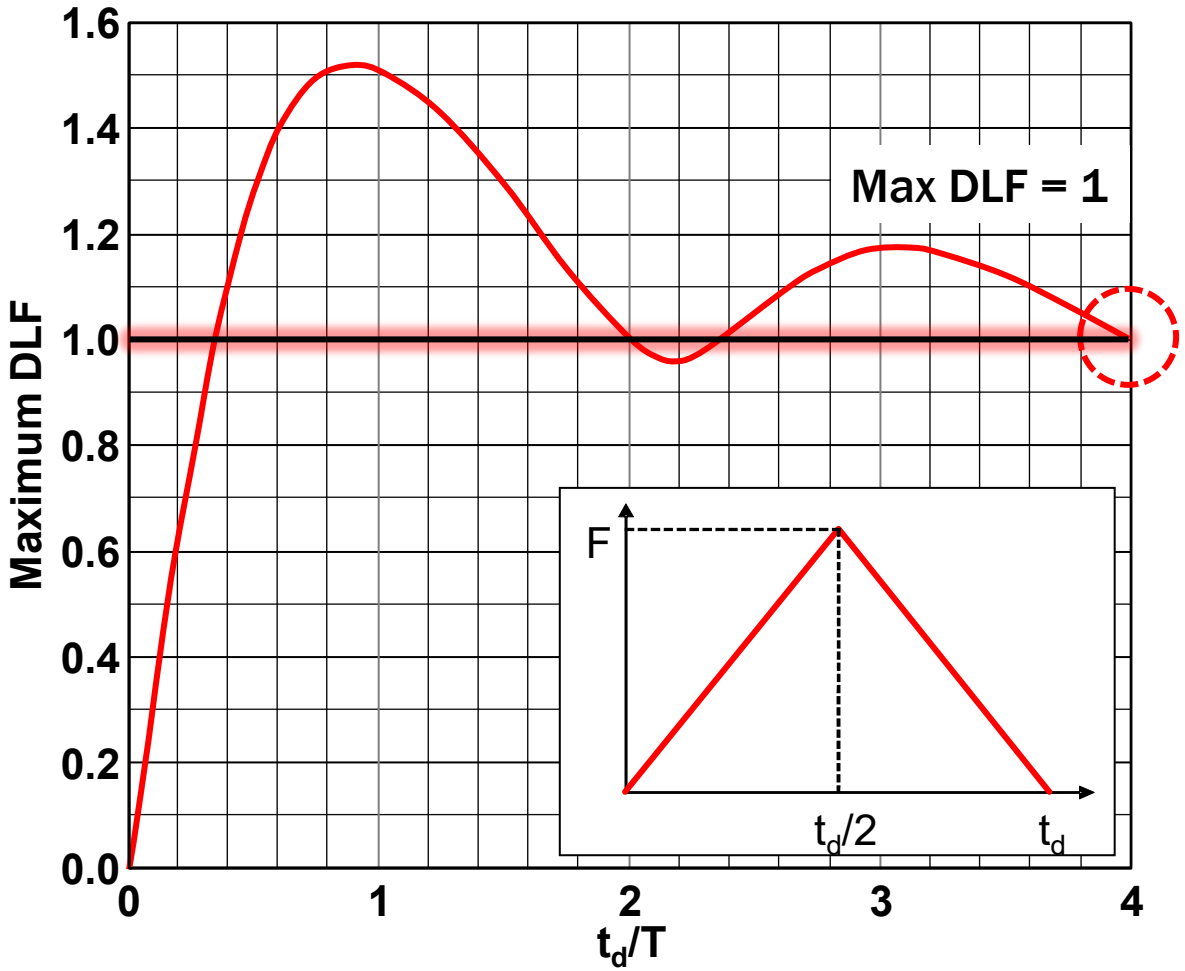
**T = 0.00972 sec**
**$t_d/T$ = 20.5**

**12.7-mm- (1/2”) thick door skin w/ grid stiffener**

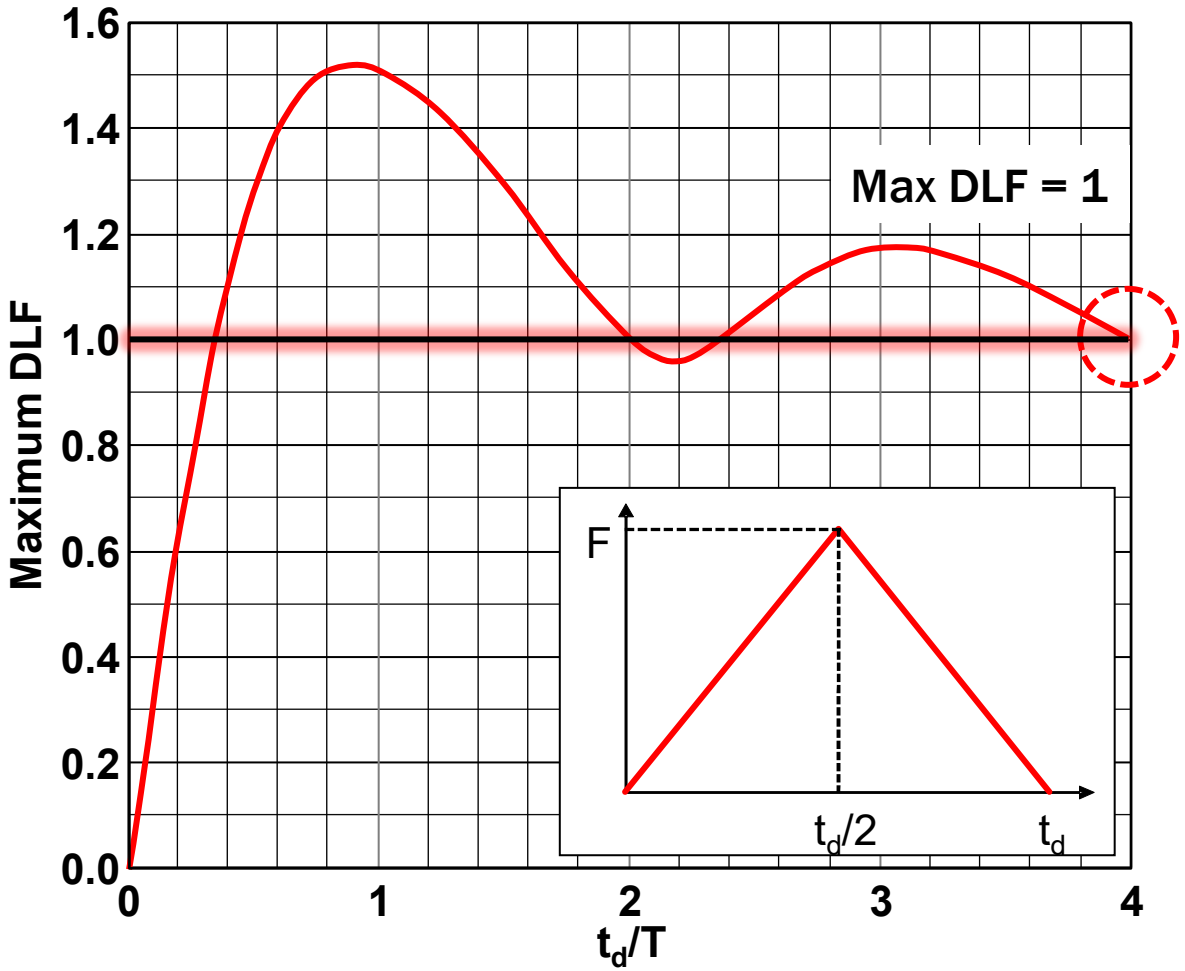


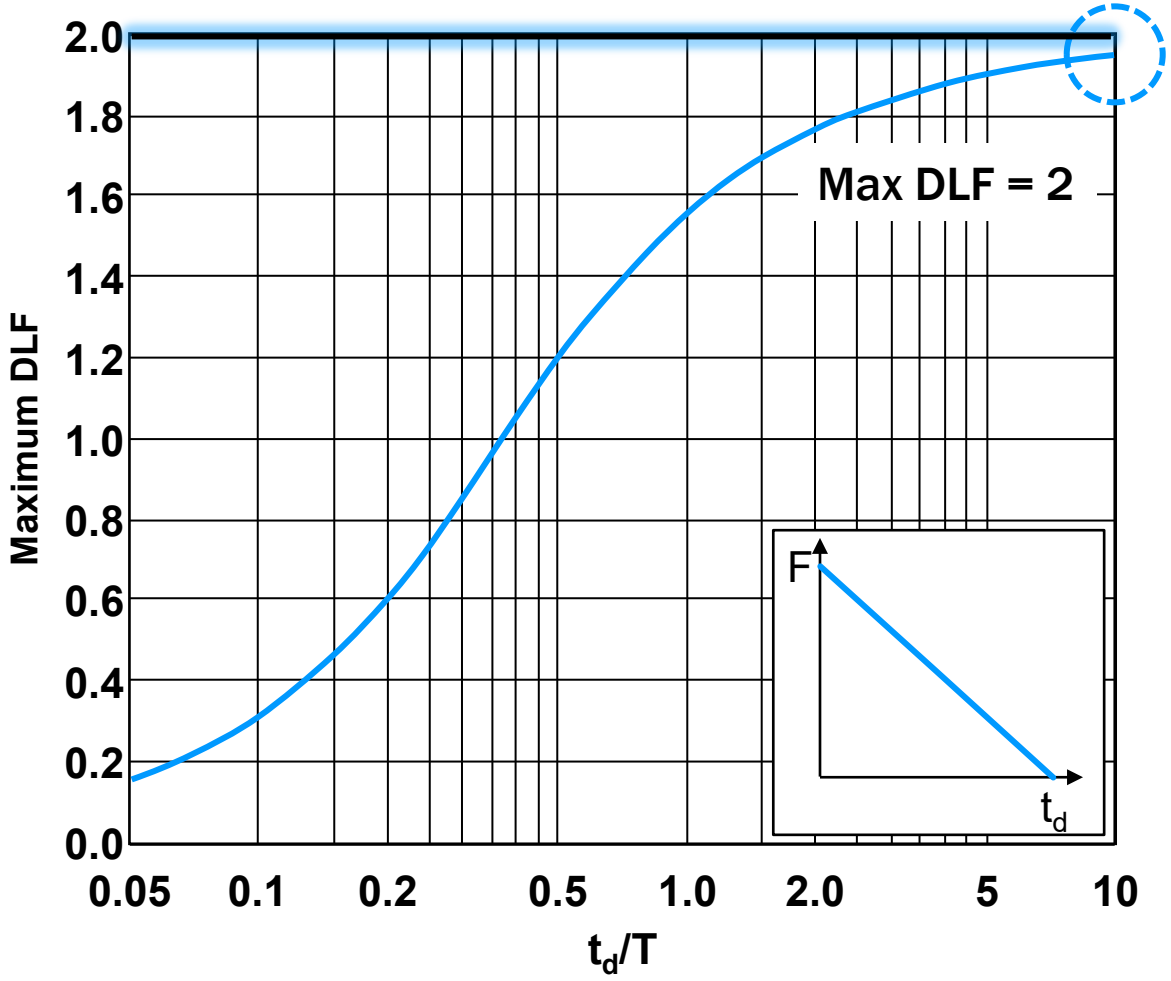
**T = 0.0113 sec**
**$t_d/T$ = 17.7**

# For all *isosceles-triangle-shaped loads*, $t_d/T$ was > 4, and the max DLF for these loads was assumed to be 1.

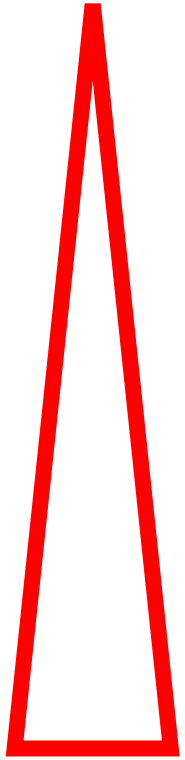


# For all *isosceles-triangle-shaped loads*, $t_d/T$ was > 4, and the max DLF for these loads was assumed to be 1. For all *right-triangle-shaped loads*, $t_d/T$ was > 10, so the max DLF for these loads was 2.



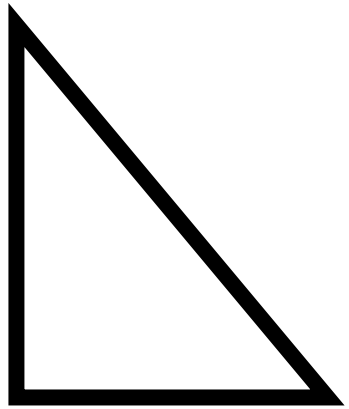
# DLF-scaled loads were calculated for each idealized blast pressure time waveform.



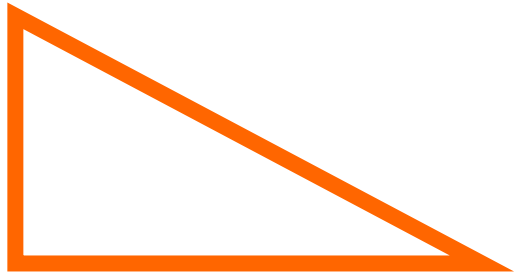
15-psi, 200-ms isosceles triangle

DLF = 1

DLF-scaled load of 15 psi

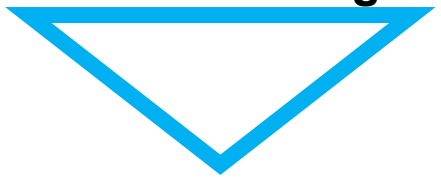


7.5-psi, 400-ms right triangle



5-psi, 600-ms right triangle

-3-psi, 500-ms isosceles triangle

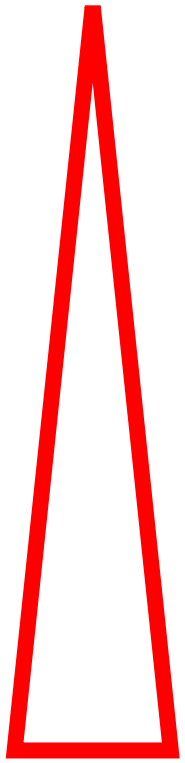


DLF = 1

DLF-scaled load of -3 psi

# DLF-scaled loads were calculated for each idealized blast pressure time waveform.

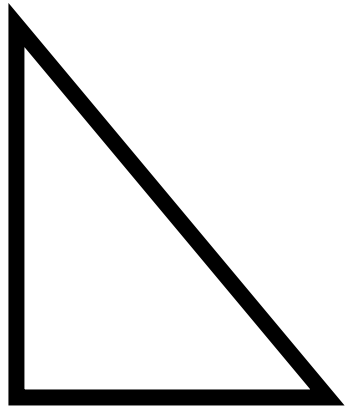
***The FE analysis was conducted with a positive 15-psi load, then a negative 3-psi load***



**15-psi, 200-ms isosceles triangle**

**DLF = 1**

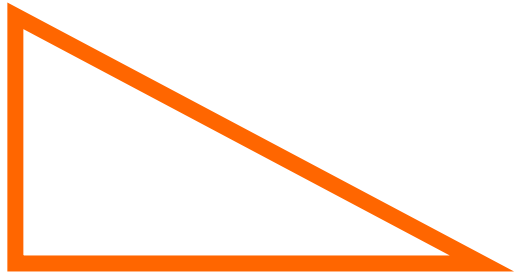
**DLF-scaled load of 15 psi**



**7.5-psi, 400-ms right triangle**

**DLF = 2**

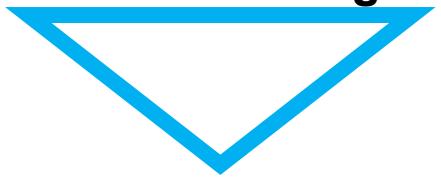
**DLF-scaled load of 15 psi**



**5-psi, 600-ms right triangle**

**DLF = 2**

**DLF-scaled load of 10 psi**



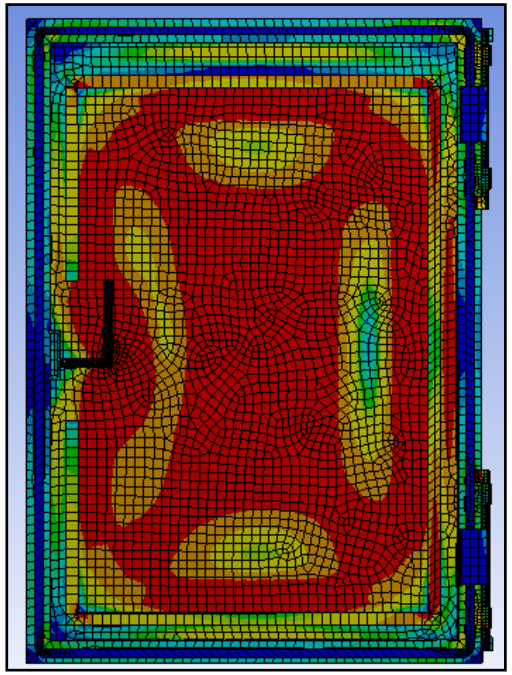
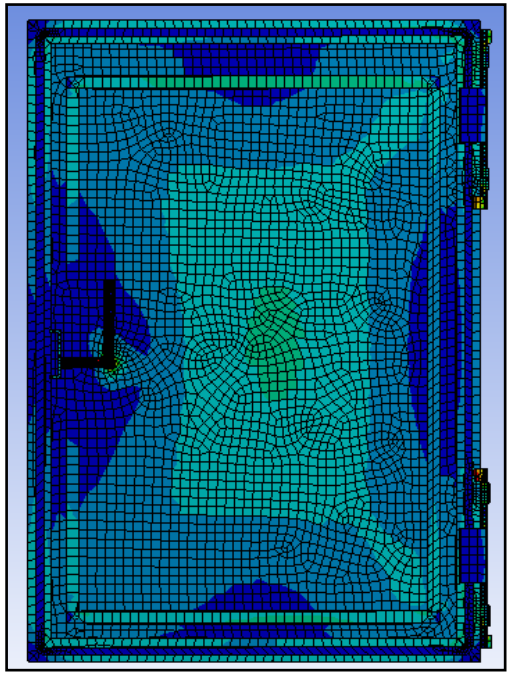
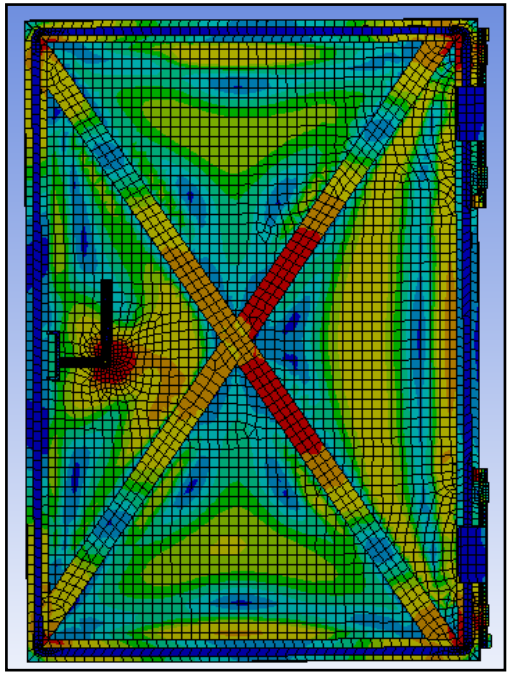
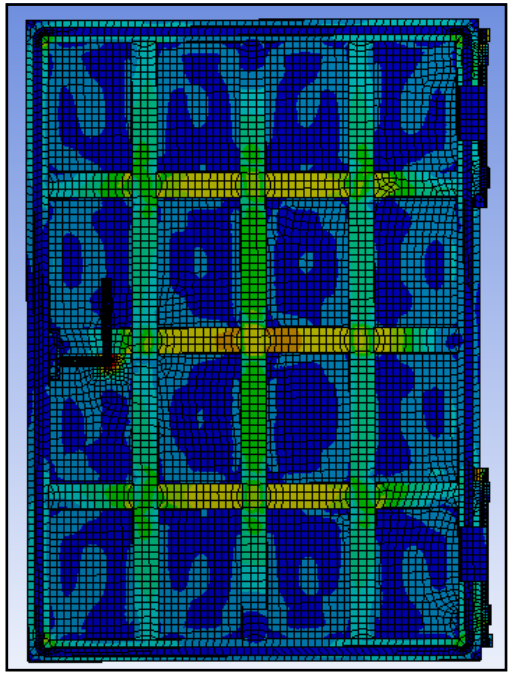
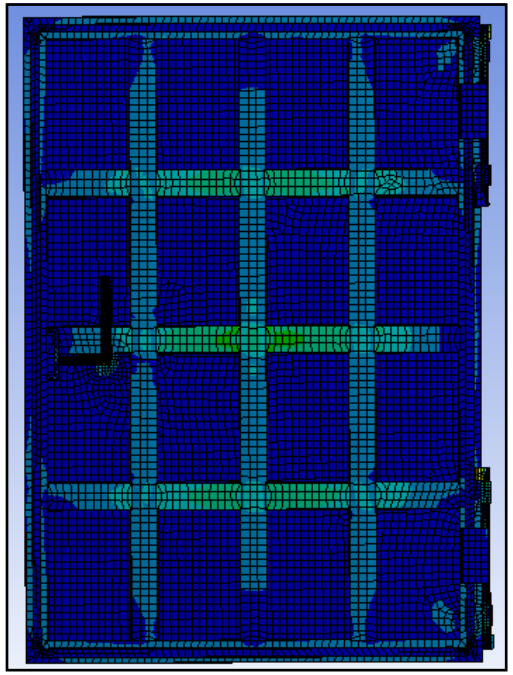
**-3-psi, 500-ms isosceles triangle**

**DLF = 1**

**DLF-scaled load of -3 psi**

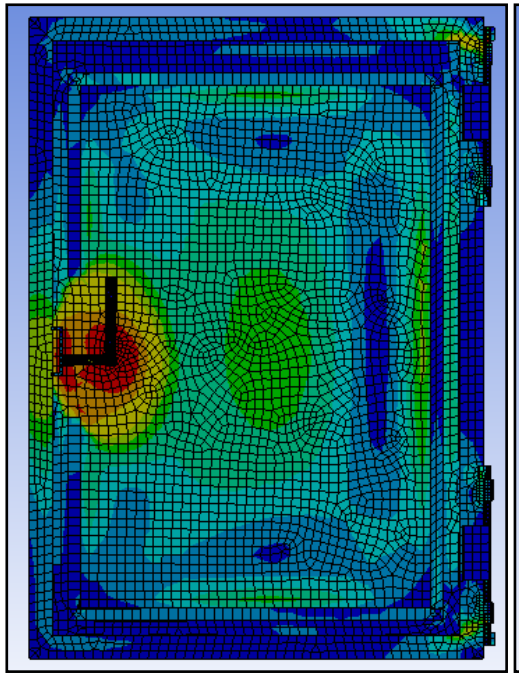
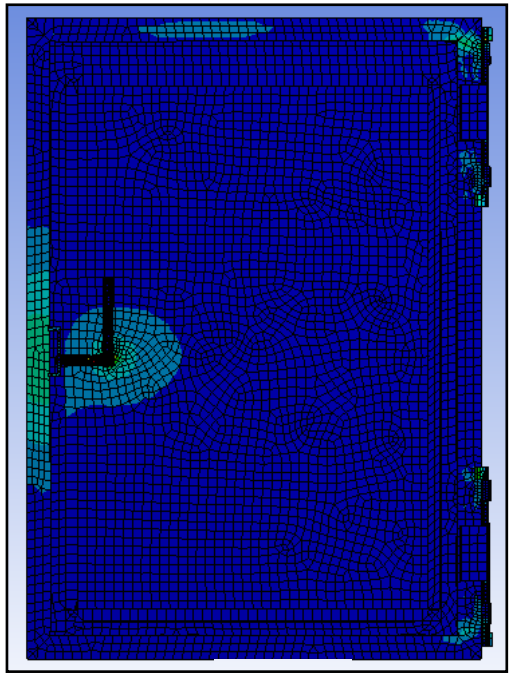
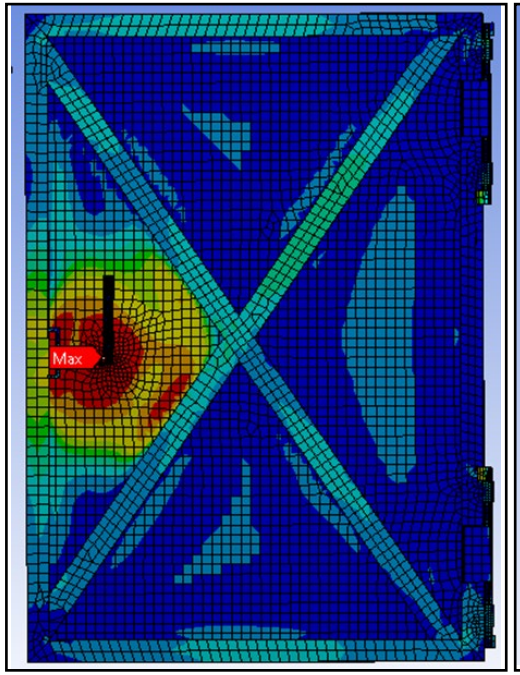
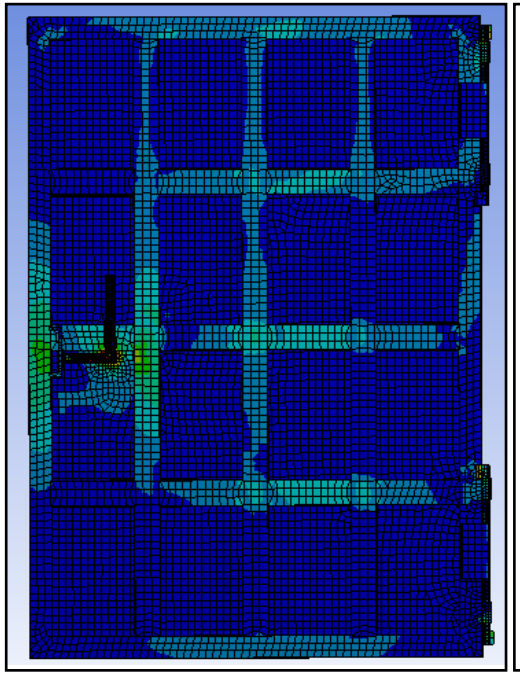
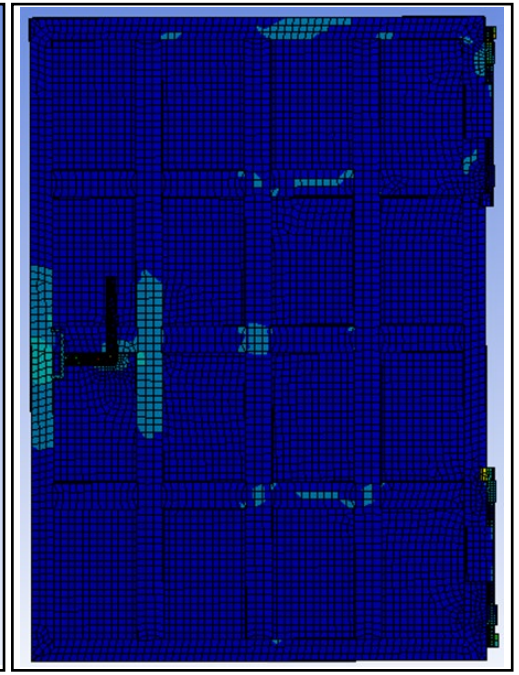
# For the positive 15-psi load, yielding was predicted on either the door skin, door skin stiffeners, or latch for all door designs except the thicker door with the grid stiffeners.

*Note: Yielding is indicated by yellow ($\sigma$ > 36 ksi), orange ($\sigma$ > 54 ksi), or red ($\sigma$ > 72 ksi)*

| As Built 3.18-mm- (1/8-in-) thick door skin | 12.7-mm- (1/2-in-) thick door skin | 3.18-mm- (1/8-in-) thick door skin w/ X-brace stiffener | 3.18-mm- (1/8-in-) thick door skin w/ grid stiffener | 12.7-mm- (1/2-in-) thick door skin w/ grid stiffener |
|---|---|---|---|---|
|  |  |  |  |  |
| Door skin: 174 ksi<br>Latch pin: 54 ksi<br>Latch plate: 61 ksi | Door skin: 20 ksi<br>Latch pin: 49 ksi<br>Latch plate: 58 ksi | Door skin: 87 ksi<br>Latch pin: 46 ksi<br>Latch plate: 47 ksi<br>Stiffener: 75 ksi | Door skin: 66 ksi<br>Latch pin: 70 ksi<br>Latch plate: 46 ksi<br>Stiffener: 59 ksi | Door skin: 23 ksi<br>Latch pin: 34 ksi<br>Latch plate: 27 ksi<br>Stiffener: 25 ksi |

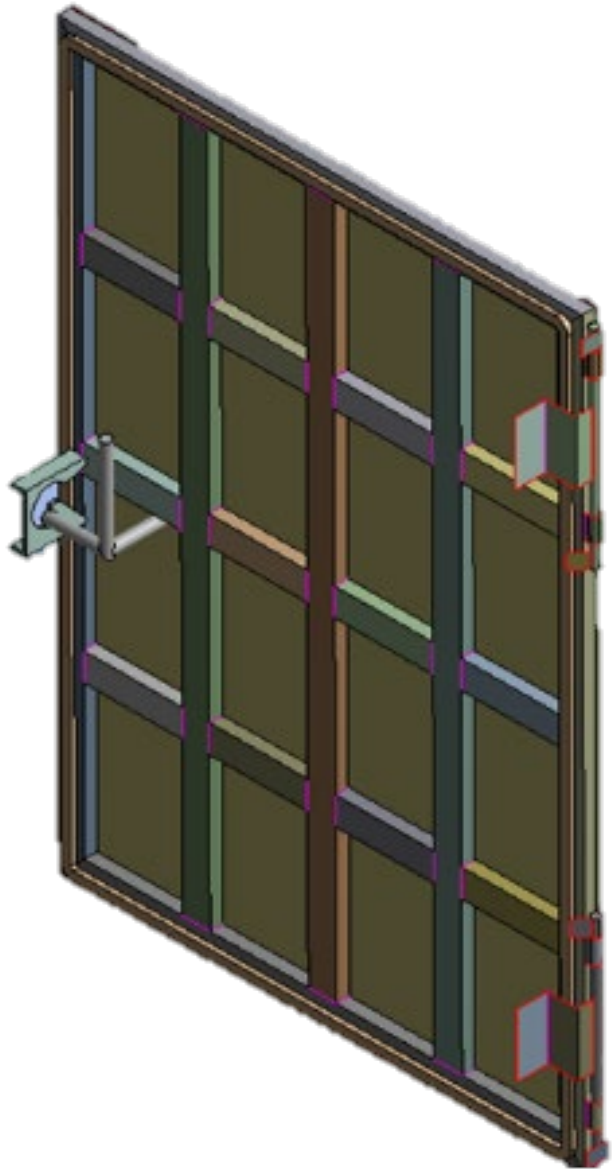
# For the negative 3-psi load, yielding was predicted on either the latch pin or latch plate for all door designs.

*Note: Yielding is indicated by yellow ($\sigma$ > 36 ksi), orange ($\sigma$ > 54 ksi), or red ($\sigma$ > 72 ksi)*

| As Built 3.18-mm- (1/8-in-) thick door skin | 12.7-mm- (1/2-in-) thick door skin | 3.18-mm- (1/8-in-) thick door skin w/ X-brace stiffener | 3.18-mm- (1/8-in-) thick door skin w/ grid stiffener | 12.7-mm- (1/2-in-) thick door skin w/ grid stiffener |
|---|---|---|---|---|
|  |  |  |  |  |
| Door skin: 77 ksi<br>Latch pin: 59 ksi<br>Latch plate: 61 ksi | Door skin: 21 ksi<br>Latch pin: 55 ksi<br>Latch plate: 63 ksi | Door skin: 62 ksi<br>Latch pin: 60 ksi<br>Latch plate: 56 ksi<br>Stiffener: 19 ksi | Door skin: 33 ksi<br>Latch pin: 73 ksi<br>Latch plate: 59 ksi<br>Stiffener: 23 ksi | Door skin: 12 ksi<br>Latch pin: 56 ksi<br>Latch plate: 52 ksi<br>Stiffener: 10 ksi |

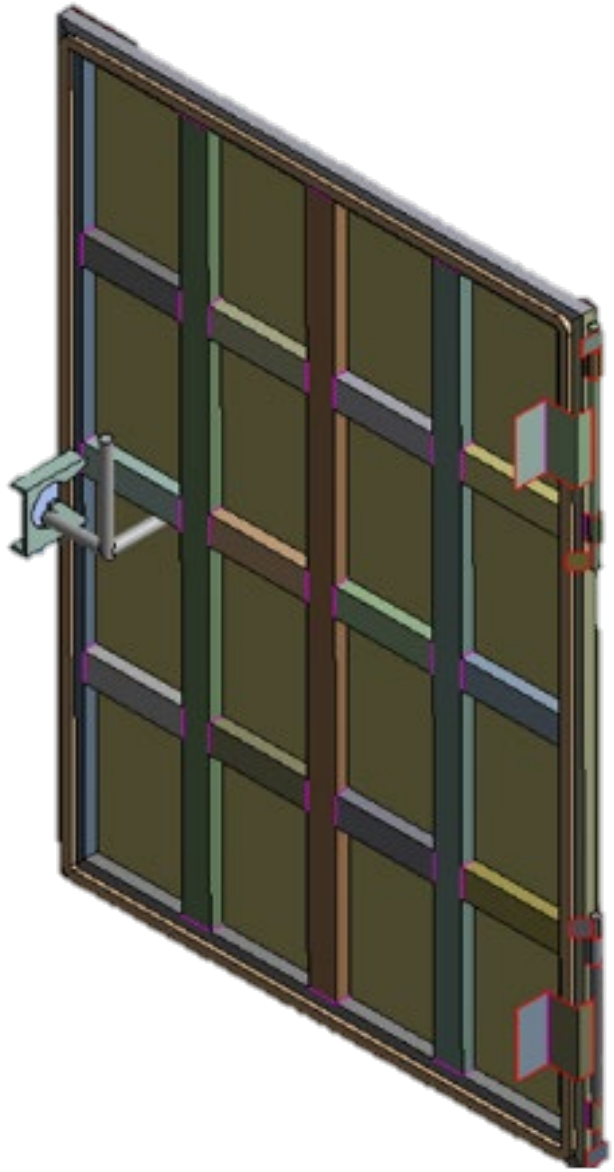
# In general, BIP RA door testing and/or analysis should

- Apply the DLF approach for design-phase analyses
- Use a door's dynamic behavior (fundamental natural frequency) with idealized blast loads to determine the DLF and the DLF-scaled loads for analysis purposes
- Examine the effects of both positive and negative pressure loading because negative loads applied to a door could cause multiple components to fail



# In order to ensure a 0.91-m (36”) wide by 1.30-m (51”) high BIP RA door can withstand a 15-psi positive load and a 3-psi negative load without yielding …

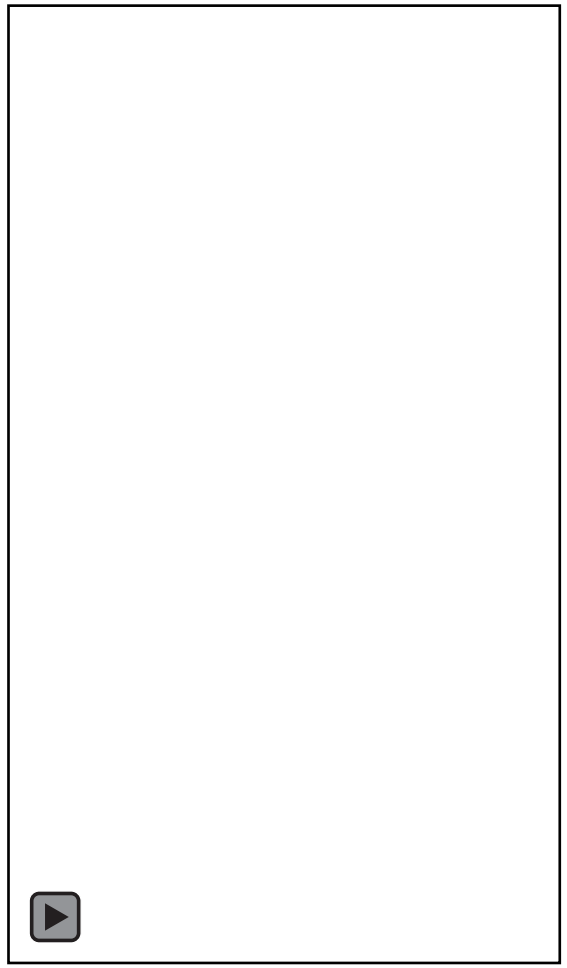
- The door skin thickness should be 12.7 mm (1/2”) or greater
- Grid stiffeners should be used to reinforce the door skin
- The latch pin diameter and the latch plate thickness should be increased
- Multiple latching mechanisms should be considered



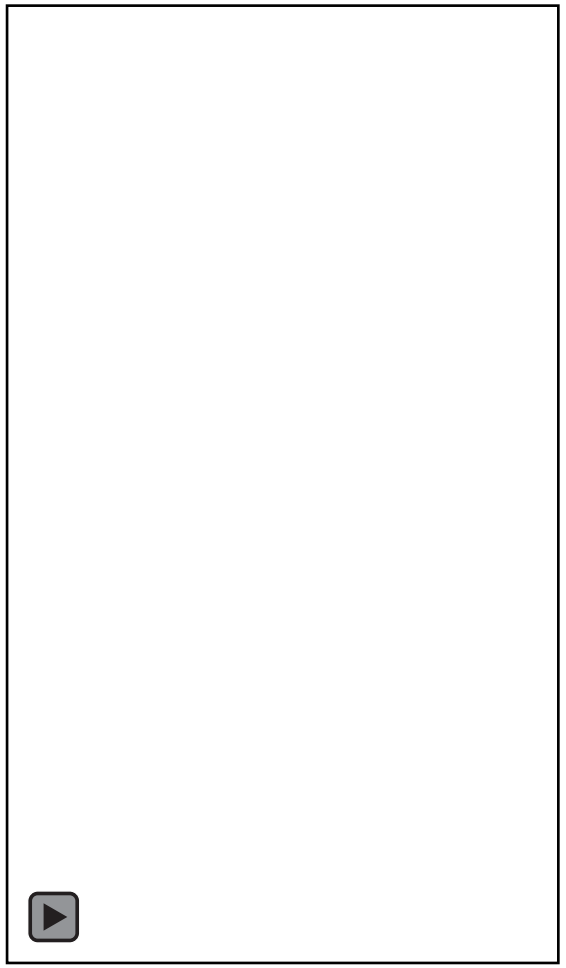
# Thank you for your attention!

## *Response to a negative 3-psi load*

Original design
3.18-mm- (1/8-in-) thick



Grid stiffeners +
12.7-mm- (1/2-in-) thick

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