Aerospace Structures Pre-Laboratory
Lab 03 Riveted Joint Design, Fabrication and Testing
Section 4 Group 2
Matthew Mehrtens
AER E 322 February 8, 2023 **Spring 2023**

Question 1

Review Week 4 lecture materials and MIL-R-47196A standard thoroughly.

Question 2

(80 pts) A pre-specified design of 2-2 rivet pattern is given in Fig. 1 for a riveted sample consisting of two overlapped 2" by 8" test panels. The thickness of each test panel is 0.025" and hole diameter (i.e. rivet diameter) is 1/8". Your first task of the prelab is to evaluate the test panel's joint efficiency for each of the four failure modes as described in Week 4 lecture notes, particularly in the workout example on pages 18-28. Which failure will happen first and why? Next, for each failure mode, predict the maximum load that can cause that type of failure. For tension failure mode, calculate the maximum load and corresponding stress for each row separately, as demonstrated in Part 3 of the workout example. Use the material properties provided below.

Based on the output of my script shown in Listing 1, here are the predicted efficiencies:

$$\begin{aligned}
\eta_s &= 0.6545 \\
\eta_b &= 0.463 \\
\eta_{to} &= 0.6667 \\
\eta_{t1} &= 0.875 \\
\eta_{t2} &= 1.75
\end{aligned}$$

Based on these efficiencies, bearing failure, η_b, will occur first since it has the lowest efficiency, *i.e.*, the system handles bearing loads the least efficiency.

The maximum loads that can cause each type of failure are listed below. These were also calculated using Listing 1.

$$
\begin{aligned}
F_s &= 883.6\,\text{lb}\\
F_b &= 625\,\text{lb}\\
F_{to} &= 900\,\text{lb}\\
F_{t1} &= 1181\,\text{lb}\\
F_{t2} &= 590.6\,\text{lb}\\
\sigma_{t1} &= 27\,\text{ksi}\\
\sigma_{t2} &= 13.5\,\text{ksi}
\end{aligned}
$$

Based on these data, the system will fail at 625 lb due to bearing failure.

Question 3

(120 pts) Based on what you find in Section 2. above, redesign the joint for better strength within the same overlapped area. You may want to consider popular rivet patterns such as 1-3-1 and 2-1-2 or higher density like 2-3-2 and 3-3-3. You can use as many rivets as you like but remember that too many rivets can actually weaken the joint (remember the design rule of thumb on page 17 of lecture notes). Calculate the joint efficiency and predict how and under what load your new design will fail in each failure mode, just like what you did in Section 2. You don't necessarily need to follow the minimum pitch and edge margins specified in MIL-R-47196A, but if you do decide to disregard standard practice, you should justify why. You will also need to be able to justify if you will take different approaches in redesigning the joint.

Using the my Rivet Analysis script, Listing 2, the best design I could come up with is a four by two pattern shown in Figure 1.

The efficiencies are listed below:

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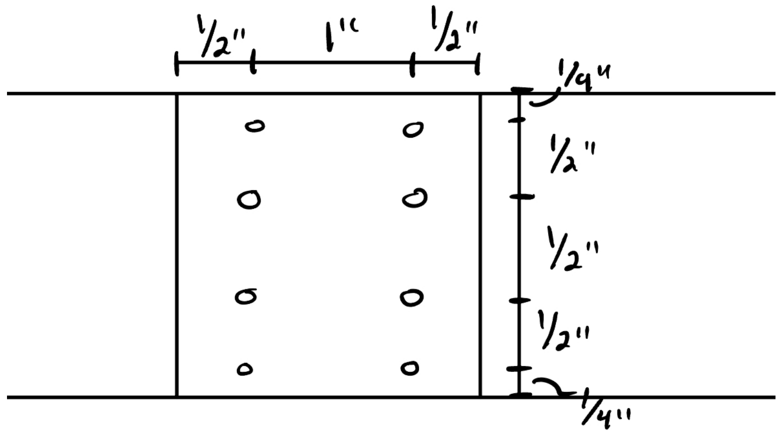

Figure 1: My rivet pattern design.

$$\eta_s = 1.309$$
$$\eta_b = 0.9259$$
$$\eta_{to} = 1.333$$
$$\eta_{t1} = 0.75$$
$$\eta_{t2} = 1.5$$

Based on these efficiencies, I expect my system to fail due to tension stress in the first row (relative to the loading) since it has the lowest efficiency of all the failure modes. The maximum loads supported by each mode of failure are:

$$F_s = 1767\,\mathrm{lb}$$
$$F_b = 1250\,\mathrm{lb}$$
$$F_{to} = 1800\,\mathrm{lb}$$
$$F_{t1} = 1012\,\mathrm{lb}$$
$$F_{t2} = 506.2\,\mathrm{lb}$$
$$\sigma_{t1} = 27\,\mathrm{ksi}$$
$$\sigma_{t2} = 13.5\,\mathrm{ksi}$$

Given these maximum forces, I estimate my rivet pattern will be able to sustain a maximum of 1012 lb before it fails due to tensile stress in the first row of rivets.

Code

```
% AER E 322 Spring 2023 Lab 03 Pre-Lab
% Matthew Mehrtens
clear, clc, close all;

% Rivet/Sheet Characteristics
d = 1/8;     % [in]
w = 2;       % [in]
t = 0.025;   % [in]

% Layout Characteristics
e = 0.5;             % [in] -- distance of rivet center from the edge
layout  = [2, 2];    % [] -- rivets in each row counting from the loaded row
N = sum(layout);     % []
N_e = layout(2);     % []

% Material Characteristics
sigma_tu    = 27*10^3;  % [psi]
sigma_bu    = 50*10^3;  % [psi]
tau_su      = 18*10^3;  % [psi]
tau_sup     = tau_su;   % [psi]

% Calculate Joint Efficiencies
eta_s   = calc_eta_shear(d, w, t, tau_su, sigma_tu, N);          % []
eta_b   = calc_eta_bearing(d, w, t, sigma_bu, sigma_tu, N);      % []
eta_to  = calc_eta_tearout(w, t, e, tau_sup, sigma_tu, N_e);     % []

eta_t1  = calc_eta_tension( ...
    d, w, t, N, sum(layout(1:0)), layout(1));    % []
eta_t2  = calc_eta_tension( ...
    d, w, t, N, sum(layout(1:1)), layout(2));    % []

% Calculate maximum load (or stress) for each failure mode
F_s         = N * tau_su * pi * d^2 / 4;            % [lb]
F_b         = N * sigma_bu * d * t;                 % [lb]
F_to        = 2 * t * e * tau_sup * N_e;            % [lb]

```

```
F_t1         = sigma_tu * (w - layout(1) * d) * t;    % [lb]
F_t2         = (N - sum(layout(1:1))) / N * F_t1;     % [lb]
sigma_t1     = F_t1 / ((w - layout(1) * d) * t);      % [psi]
sigma_t2     = F_t2 / ((w - layout(2) * d) * t);      % [psi]

% Print out the efficiencies
fprintf(['\x03B7_s  = %6.4g []\n' ...
         '\x03B7_b  = %6.4g []\n' ...
         '\x03B7_to = %6.4g []\n' ...
         '\x03B7_t1 = %6.4g []\n' ...
         '\x03B7_t2 = %6.4g []\n'], eta_s, eta_b, eta_to, eta_t1, eta_t2);

fprintf('\n');

% Print out the maximum loads for each failure mode
fprintf(['F_s  = %6.4g [lb]\n' ...
         'F_b  = %6.4g [lb]\n' ...
         'F_to = %6.4g [lb]\n' ...
         'F_t1 = %6.4g [lb]\n' ...
         'F_t2 = %6.4g [lb]\n' ...
         '\x03C3_t1 = %6.4g [ksi]\n' ...
         '\x03C3_t2 = %6.4g [ksi]\n'], ...
         F_s, F_b, F_to, F_t1, F_t2, sigma_t1 / 1000, sigma_t2 / 1000);
```

Listing 1: Question 2 Script: `Rivet-Analysis-2by2.m`.

```
% AER E 322 Spring 2023 Lab 03 Pre-Lab
% Matthew Mehrtens
clear, clc, close all;

% Rivet/Sheet Characteristics
d = 1/8;     % [in]
w = 2;       % [in]
t = 0.025;   % [in]

% Layout Characteristics
e = 1/2;            % [in] -- distance of rivet center from the edge
layout = [4, 4];    % [] -- rivets in each row counting from the loaded row
N = sum(layout);    % []
N_e = layout(2);    % []

% Material Characteristics
```

```
sigma_tu     = 27*10^3;   % [psi]
sigma_bu     = 50*10^3;   % [psi]
tau_su       = 18*10^3;   % [psi]
tau_sup      = tau_su;    % [psi]

% Calculate Joint Efficiencies
eta_s    = calc_eta_shear(d, w, t, tau_su, sigma_tu, N);             % []
eta_b    = calc_eta_bearing(d, w, t, sigma_bu, sigma_tu, N);         % []
eta_to   = calc_eta_tearout(w, t, e, tau_sup, sigma_tu, N_e);        % []

eta_t1   = calc_eta_tension( ...
    d, w, t, N, sum(layout(1:0)), layout(1));    % []
eta_t2   = calc_eta_tension( ...
    d, w, t, N, sum(layout(1:1)), layout(2));    % []
%eta_t3   = calc_eta_tension( ...
    %d, w, t, N, sum(layout(1:2)), layout(3));    % []

% Calculate maximum load (or stress) for each failure mode
F_s          = N * tau_su * pi * d^2 / 4;             % [lb]
F_b          = N * sigma_bu * d * t;                  % [lb]
F_to         = 2 * t * e * tau_sup * N_e;             % [lb]

F_t1         = sigma_tu * (w - layout(1) * d) * t;    % [lb]
F_t2         = (N - sum(layout(1:1))) / N * F_t1;     % [lb]
%F_t3         = (N - sum(layout(1:2))) / N * F_t1;     % [lb]
sigma_t1     = F_t1 / ((w - layout(1) * d) * t);      % [psi]
sigma_t2     = F_t2 / ((w - layout(2) * d) * t);      % [psi]
%sigma_t3     = F_t3 / ((w - layout(3) * d) * t);      % [psi]

% Print out the efficiencies
fprintf(['\x03B7_s   = %6.4g []\n' ...
         '\x03B7_b   = %6.4g []\n' ...
         '\x03B7_to  = %6.4g []\n' ...
         '\x03B7_t1  = %6.4g []\n' ...
         '\x03B7_t2  = %6.4g []\n'], ...
         eta_s, eta_b, eta_to, eta_t1, eta_t2);

fprintf('\n');

% Print out the maximum loads for each failure mode
fprintf(['F_s   = %6.4g [lb]\n' ...
         'F_b   = %6.4g [lb]\n' ...
         'F_to  = %6.4g [lb]\n' ...
```

```
        'F_t1 = %6.4g [lb]\n' ...
        'F_t2 = %6.4g [lb]\n' ...
        '\x03C3_t1 = %6.4g [ksi]\n' ...
        '\x03C3_t2 = %6.4g [ksi]\n'], ...
        F_s, F_b, F_to, F_t1, F_t2, ...
        sigma_t1 / 1000, sigma_t2 / 1000);
```

Listing 2: Question 3 Script: `Rivet-Analysis-Designed.m`.

```
function eta_s = calc_eta_shear(d, w, t, tau_su, sigma_tu, N)
%CALC_ETA_SHEAR Calculates the joint efficiency with respect to shear
%failure
%   Input Arguments:
%       d:          diameter of an individual rivet [in]
%       w:          width of each sheet [in]
%       t:          thickness of each sheet [in]
%       tau_su:     ultimate shearing stress of rivets [psi]
%       sigma_tu:   ultimate stress of plates/sheets in tension [psi]
%       N:          number of rivets []
A_r     = pi * d^2 / 4; % [in^2]
A_sheet = w * t; % [in^2]
eta_s   = A_r * tau_su * N / (A_sheet * sigma_tu); % []
end
```

Listing 3: Function to calculate η_s: `calc-eta-shear.m`.

```
function eta_b = calc_eta_bearing(d, w, t, sigma_bu, sigma_tu, N)
%CALC_ETA_SHEAR Calculates the joint efficiency with respect to bearing
%failure
%   Input Arguments:
%       d:          diameter of an individual rivet [in]
%       w:          width of each sheet [in]
%       t:          thickness of each sheet [in]
%       sigma_bu:   ultimate bearing stress between rivets and sheets [psi
    ]
%       sigma_tu:   ultimate stress of plates/sheets in tension [psi]
%       N:          number of rivets []
A_proj_contact  = d * t; % [in^2]
A_sheet         = w * t; % [in^2]
eta_b           = A_proj_contact * sigma_bu * N / ...
                    (A_sheet * sigma_tu); % []
```

```
end
```

Listing 4: Function to calculate η_b: calc-eta-bearing.m.

```
function eta_to = calc_eta_tearout(w, t, e, tau_sup, sigma_tu, N_e)
%CALC_ETA_SHEAR Calculates the joint efficiency with respect to tearout
%failure
%   Input Arguments:
%       w:          width of each sheet [in]
%       t:          thickness of each sheet [in]
%       e:          distance of rivet center from the edge [in]
%       tau_sup:    ultimate shearing stress of plate [psi]
%       sigma_tu:   ultimate stress of plates/sheets in tension [psi]
%       N_e:        number of rivets in row closest to the edge of either
%                   plate []
A_sheet = w * t; % [in^2]
eta_to = 2 * t * e * tau_sup * N_e / (A_sheet * sigma_tu); % []
end
```

Listing 5: Function to calculate $\eta_t o$: calc-eta-tearout.m.

```
function eta_t = calc_eta_tension(d, w, t, N, n, N_row)
%CALC_ETA_SHEAR Calculates the joint efficiency with respect to tension
%failure
%   Input Arguments:
%       d:          diameter of an individual rivet [in]
%       w:          width of each sheet [in]
%       t:          thickness of each sheet [in]
%       N:          total number of rivets []
%       n:          total number of rivets in all previous rows []
%       N_row:      total number of rivets in the current row []
A_net   = (w - d * N_row) * t; % [in^2]
A_sheet = w * t; % [in^2]
eta_t   = A_net / ((N - n) / N * A_sheet); % []
end
```

Listing 6: Function to calculate η_t: calc-eta-tension.m.