1.

1.

a) $f_d = f_r - f_t$

$v = 300$

$f_t = 1\,GHz = 10^9\,Hz$

$c = 3 \times 10^8\ m/s$

$f_d = 2v\frac{f_t}{c}$

$= \frac{2(300)(10^9)}{3 \times 10^8}$

$\boxed{f_d = 2000\ Hz}$

b) $T \approx \frac{1}{f_d}$

$= \frac{1}{2000}$

$= 0.0005$

$\boxed{T = 0.5\ ms}$

c) $f_s = 2\,GHz = 2 \times 10^9$

$T = 5 \times 10^{-4}$

$N = f_s \times T$

$= (2 \times 10^9)(5 \times 10^{-4})$

$= 1 \times 10^6$

$\boxed{N = 1{,}000{,}000 \text{ samples}}$

2.

2.

a) $\Delta t \cdot k = \frac{\Delta f}{\Delta t} \cdot \Delta t$ $\Delta t = \frac{2R}{c}$

$\Delta f = k \Delta t$

$\frac{1}{k} \Delta f = k \cdot \frac{2R}{c} \cdot \frac{1}{k}$

$\frac{c}{2} \cdot \frac{\Delta f}{k} = \frac{2R}{c} \cdot \frac{c}{2}$

$\boxed{R = \frac{c \Delta f}{2k}}$

b) $\Delta f = 25$ MHz

$k = 1$ MHz/μs

$c = 300$ m MHz

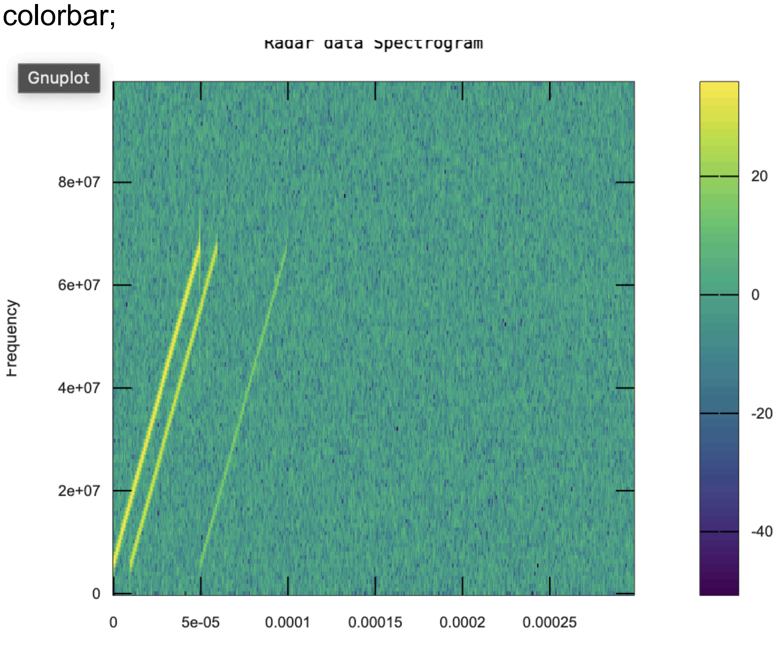
$$R = \frac{c\Delta f}{2k} = \frac{(300)(25)}{2(1)} = 150 \times 25 = 3750\,\text{m}$$

$$\boxed{R = 3.75\,\text{km}}$$

3.

```
data = load('doppler_shift.dat');
t = data(:,1);
signal = data(:,2);

dt = t(2) - t(1);
Fs = 1 / dt;
figure;
specgram(signal, 256, Fs);
title('Radar data Spectrogram');
xlabel('Time');
ylabel('Frequency');
colorbar;
```



4.

a)

```
overlap_time_us = ...;
[~, time_index] = min(abs(T * 1e6 - overlap_time_us));

power_spectrum_at_overlap = P(:, time_index);
[peaks, peak_indices] = findpeaks(power_spectrum_at_overlap);
peak_frequencies_kHz = F(peak_indices) / 1e3;

disp(['Peak frequencies at overlap ', num2str(peak_frequencies_kHz), ' kHz']);
if length(peak_frequencies_kHz) >= 2
   delta_f_kHz = abs(peak_frequencies_kHz(1) - peak_frequencies_kHz(2));
   delta_f_MHz = delta_f_kHz / 1000;
   disp([' Delta f: ', num2str(delta_f_MHz), ' MHz']);
end
```

4.

a) at $t = 40\,\mu s = 4\times10^{-5}$

$\Delta f = f_{echo} - f_{trans}$

$= |5.2\times10^{7} - 6\times10^{7}|$

$= 0.8\times10^{7}$

$\boxed{\Delta f = 8\,\text{MHz}}$

b) $R = \frac{c\Delta f}{2k} = \frac{cT}{2}$

$= \frac{(3\times10^{8})(45\times10^{-6})}{2}$

$= 6750\,m$

$\boxed{R = 6.75\,km}$

c) $R = \frac{(3\times10^{8})(75\times10^{-6})}{2}$

$= \frac{22500}{2}$

$= 11250$

$\boxed{R = 11.25\,km}$

2 Linear Image Processing

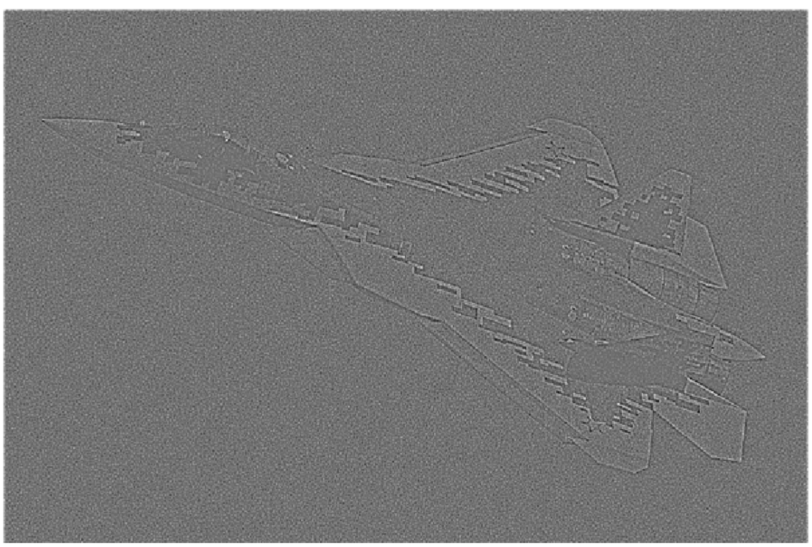
a)

```
img = imread('aircraft_data.jpg');
```

b)

```
img = imread('aircraft_data.jpg');
img = double(img);

mean_filter = ones(3,3)/9;
smoothed_img = conv2(img, mean_filter, 'same');
laplacian_filter = [0 -1 0; -1 4 -1; 0 -1 0];
edges = conv2(smoothed_img, laplacian_filter, 'same');
edges = uint8(255 * mat2gray(edges));
imshow(edges);
```



c)

The number is 054.

d)

This is a sukhoi su-57 which is a Russian fighter jet.

3 Audio Processing

a)

```
load('doppler_shift.dat');
Fs = 48000;
T = 1.0;
t = linspace(0, T, Fs * T);

f0_1 = 2000;  f1_1 = 8000;
f0_2 = 2500;  f1_2 = 8500;
chirp1 = chirp(t, f0_1, T, f1_1);
chirp2 = chirp(t, f0_2, T, f1_2);

signal = chirp1 + chirp2;
noisy_signal = signal + 0.2 * randn(size(signal));
noisy_signal = noisy_signal / max(abs(noisy_signal));
```

b)

```
f_low = 1500;
f_high = 9000;
[b, a] = butter(4, [f_low, f_high] / (Fs / 2), 'bandpass');
filtered_signal = filter(b, a, noisy_signal);
```

c)

```
disp("playing filtered audio");
sound(filtered_signal, Fs);

figure;
spectrogram(filtered_signal, 256, 200, 512, Fs, 'yaxis');
title("Spectrogram of filtered radar audio");
xlabel("time ");
ylabel("Frequency ");
```

Yes it produces two chirps that make a beat frequency.