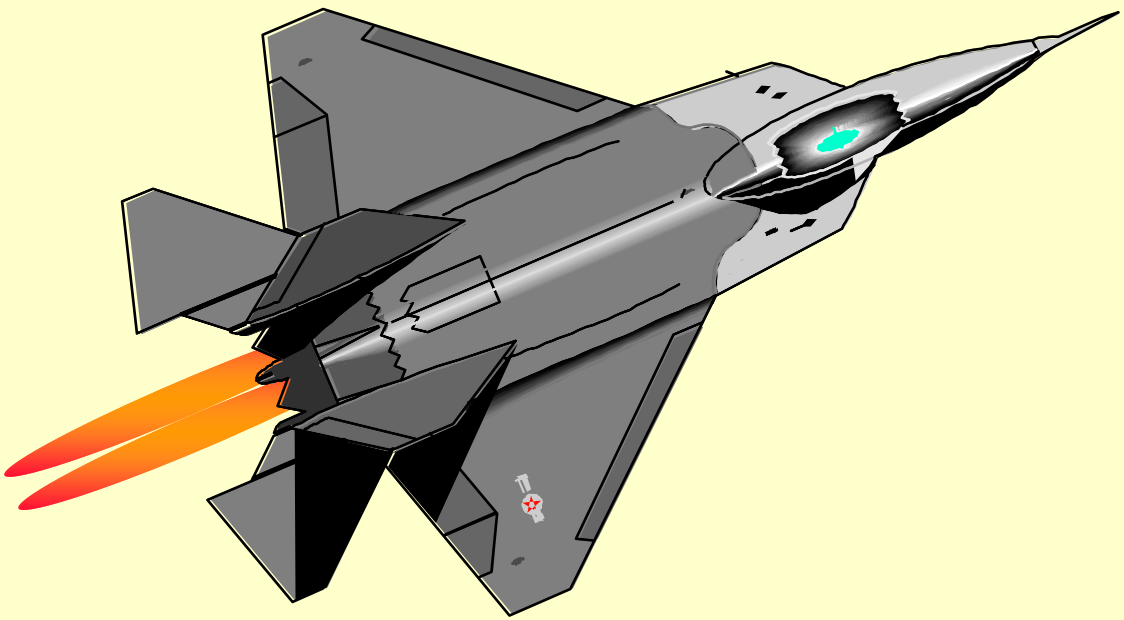
The Air Force Research Laboratory (AFRL)

Probability over Serbian Skies

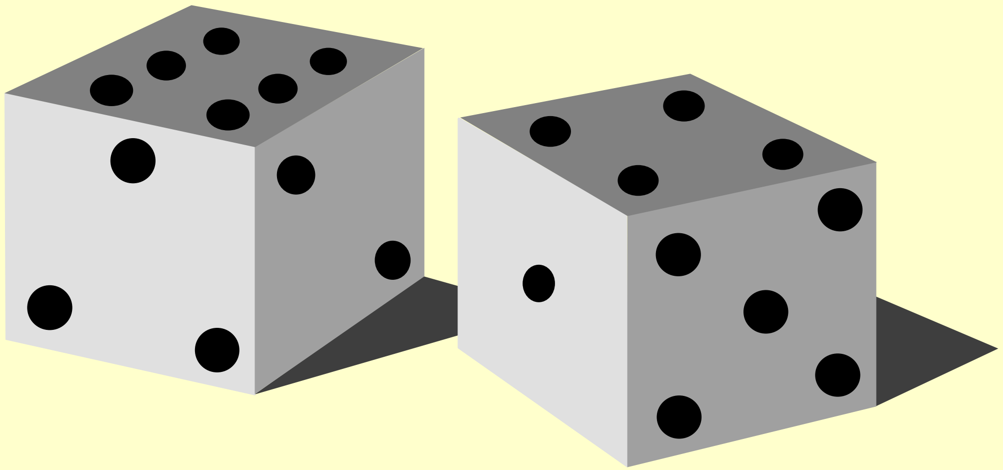
John C. Sparks

Today's USAF has Very Few Wartime Losses!

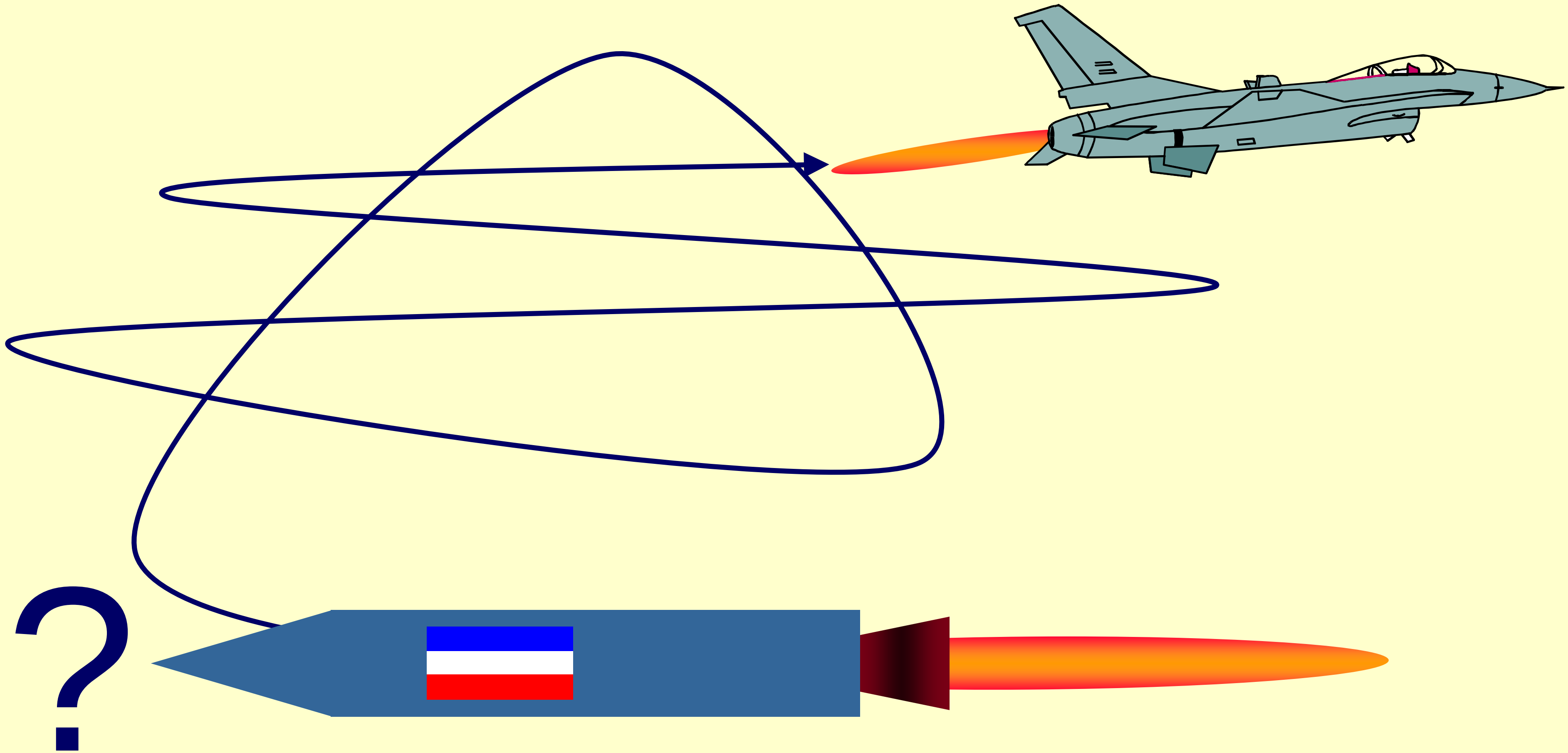


This is True by Design, And not by Chance!

Yet modern aircraft design utilizes the basic rules of probability to ensure aircraft survivability in battle.



How is this Achieved?

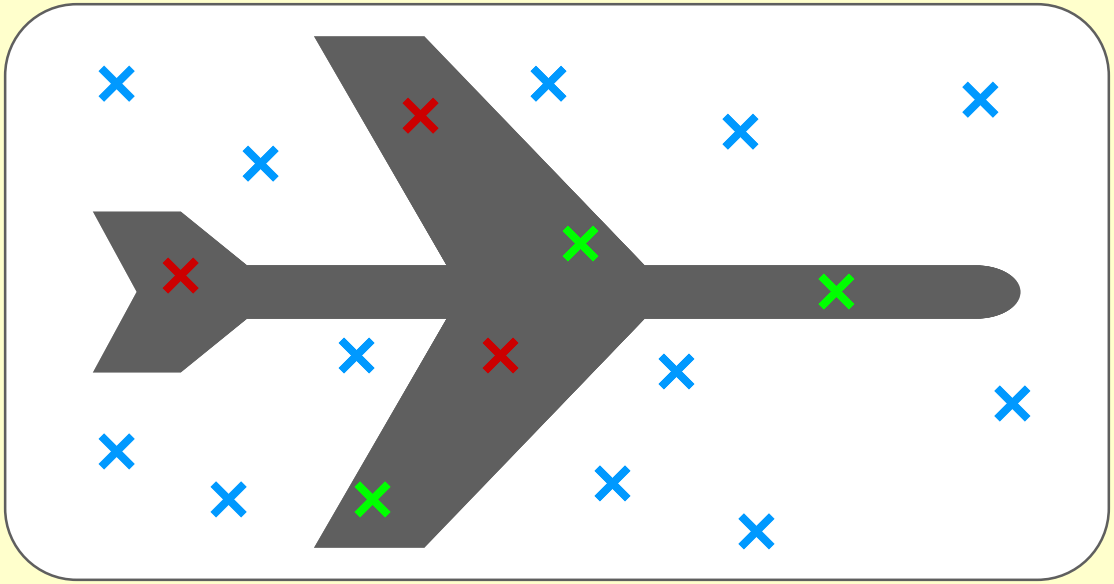


By Realizing Two Simple Facts

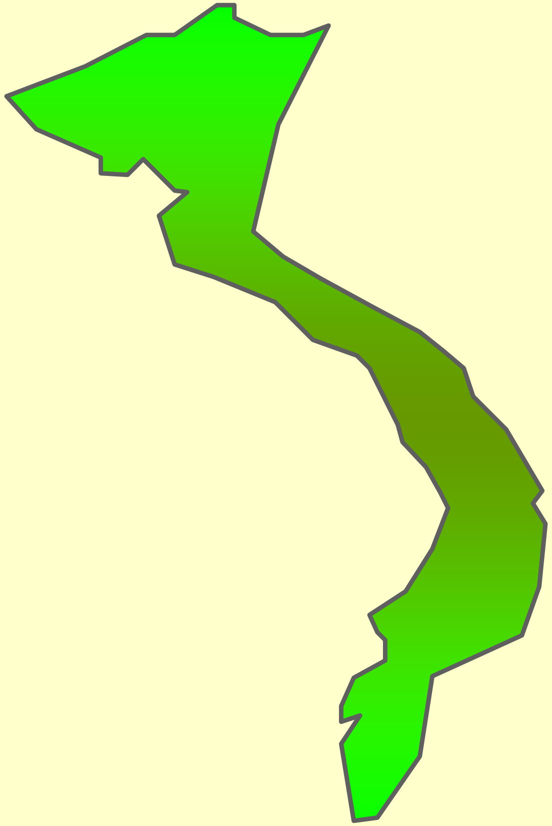
1) For an aircraft to have a chance to be killed by enemy fire, it first must be hit.

2) Once hit, vulnerable components must be damaged if the aircraft is to die.

- No hit
- Hit and not killed
- Hit and killed



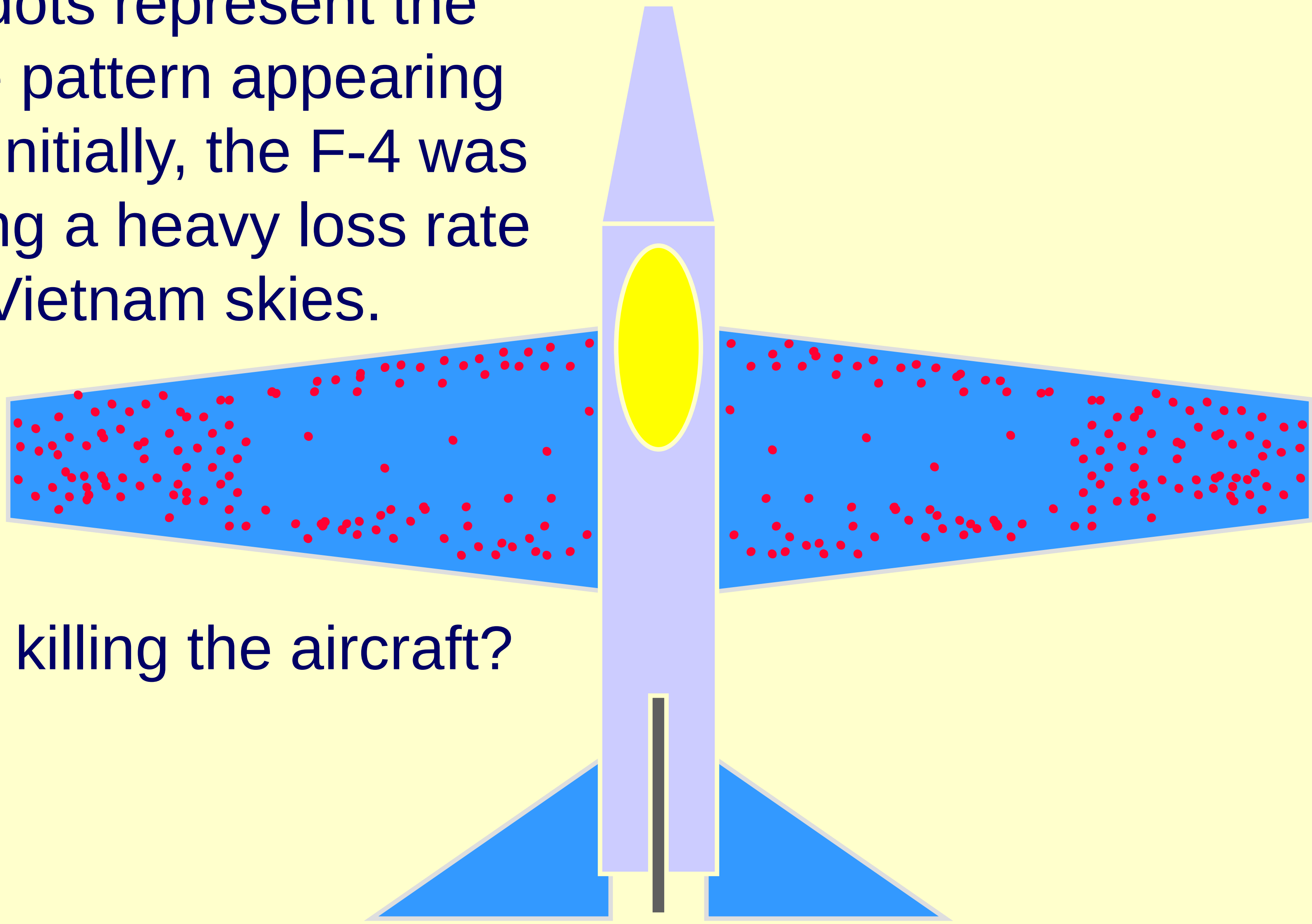
Beginnings: An Actual Vietnam Experience



McDonnell Douglas
F-4 “Phantom II”

Notional Bullet-hole Pattern On Returning F-4 Wings

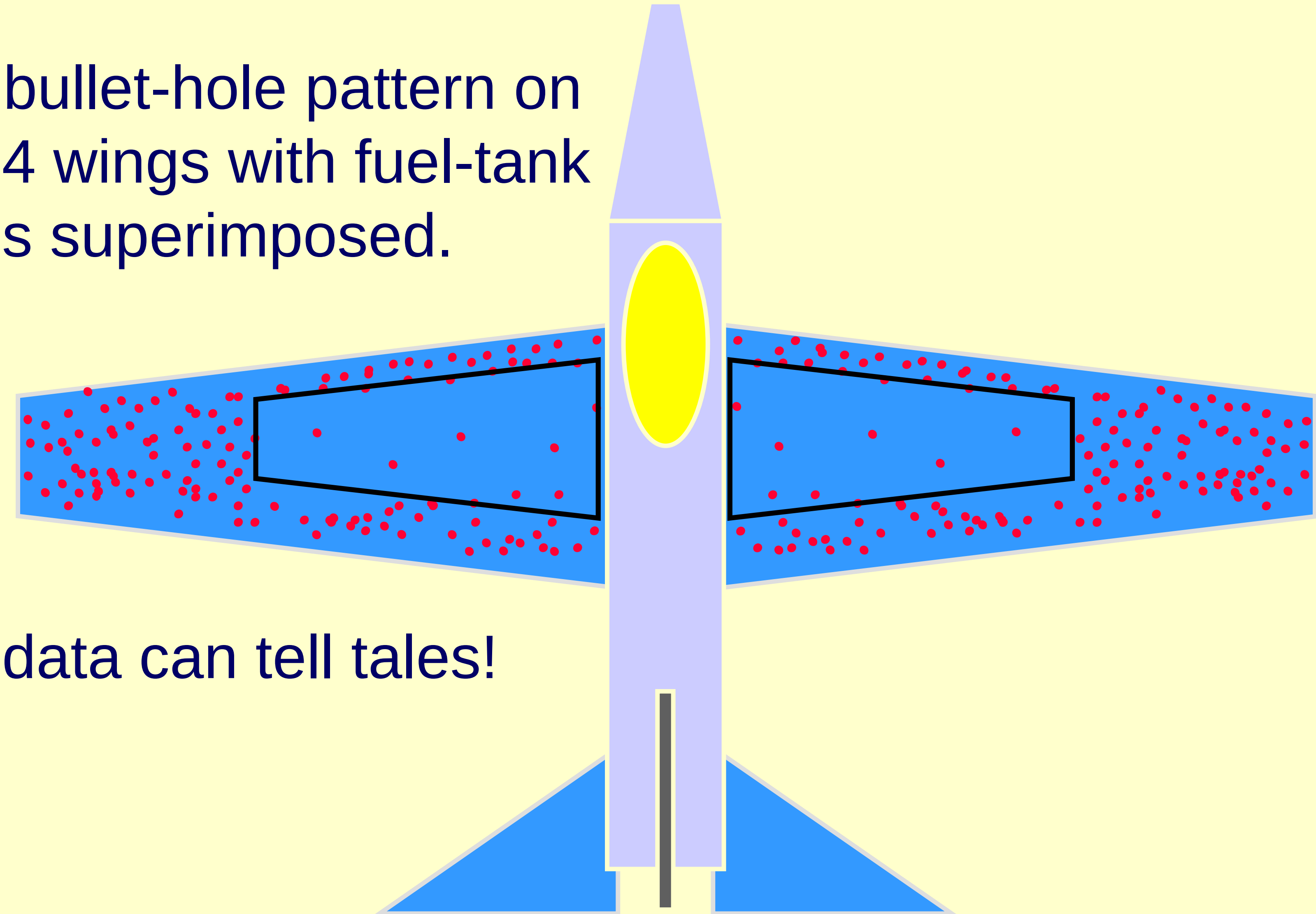
The red dots represent the composite pattern appearing over time. Initially, the F-4 was experiencing a heavy loss rate over Vietnam skies.



What was killing the aircraft?

Answer: Enemy Hits in the F-4 Fuel Tank

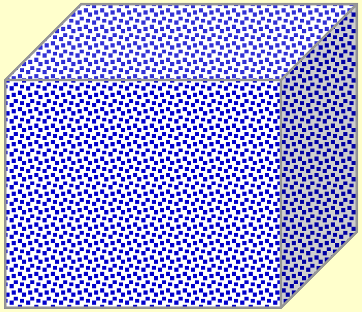
Composite bullet-hole pattern on returning F-4 wings with fuel-tank outlines superimposed.



Missing data can tell tales!

The Birth of Aircraft Survivability

- Void-filler foam was added to the F-4 fuel tanks
  - Foam attenuated overpressure due to explosion
  - Foam retarded fire propagation
- The foam did incur a weight penalty
  - But the results were well worth it!



- There was a dramatic reduction in the number of F-4 losses due to fuel-tank hits.
- Aircraft survivability increased--by design!

We will Start with Some Basic Definitions

- P_H is the probability of a hit
- P_K is the probability of a kill
- $P_{K/H}$ is the probability of a kill given a hit
- A_V is the presented vulnerable area
- A_T is the presented total area
- P_S is the overall probability of aircraft survival

The Fundamental Aircraft Survivability Equations

$$1)\ P_K = P_H * (A_V / A_T) * P_{K/H}$$

$$2)\ P_S = 1 - P_K$$

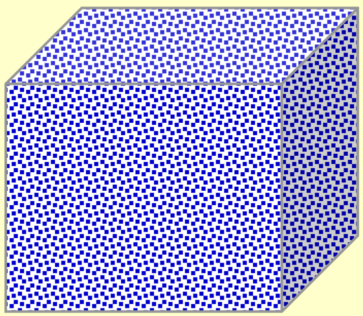
How are P_H, $P_{K/H}$, and A_V/A_T Determined?

- P_H and $P_{K/H}$ are determined using:
  - Comparison to known weapon systems
  - Live-fire test data
  - Actual combat data
  - Deterministic analysis
  - Probabilistic modeling and computer simulation
  - Educated guesses
- A_V/A_T is determined using basic geometry

How can we Increase P_S?

There are three common methods.

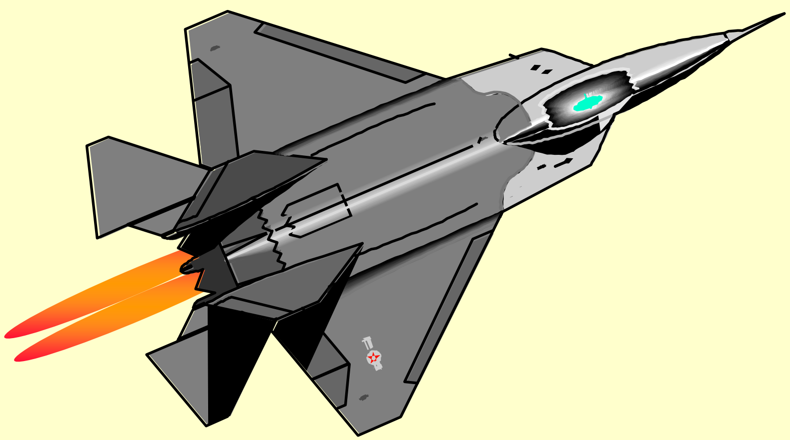
- We can reduce P_H
- We can reduce the ratio A_V/A_T
- We can reduce $P_{K/H}$



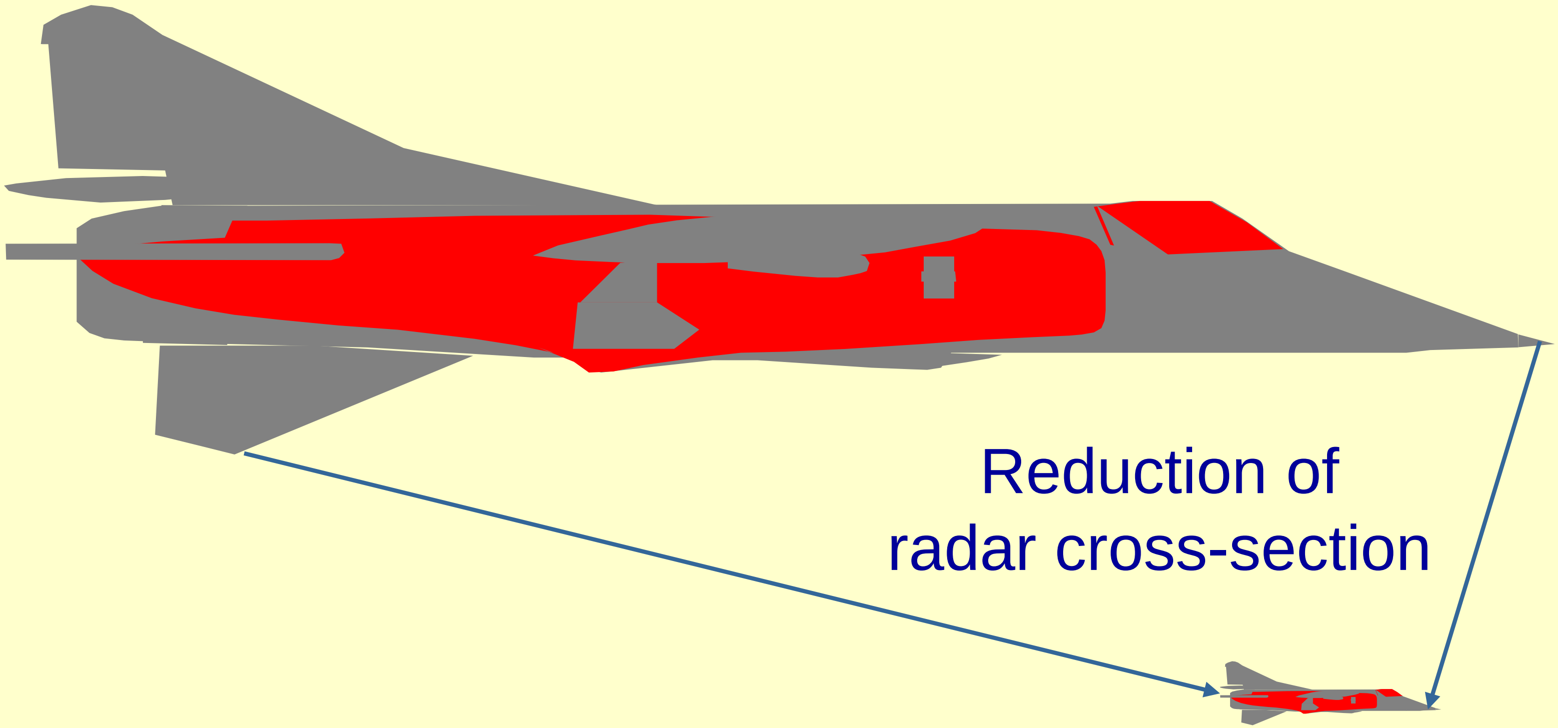
Question: installing void-filler foam in the F-4 wing tanks represented which one of the three?

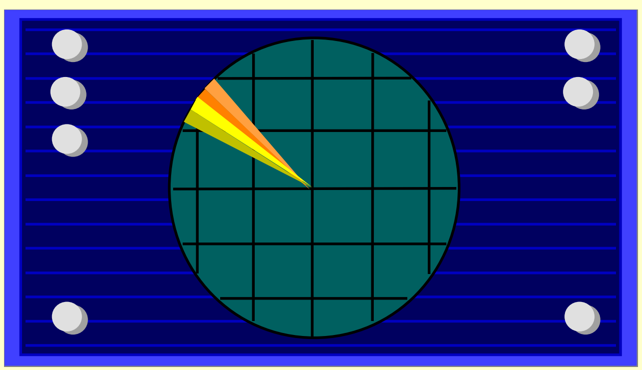
P_H is Reduced by The Following Methods

- By stealth technology
- By threat countermeasures such as decoys and jamming
- By high maneuverability



Reducing P_H by Stealth Technology



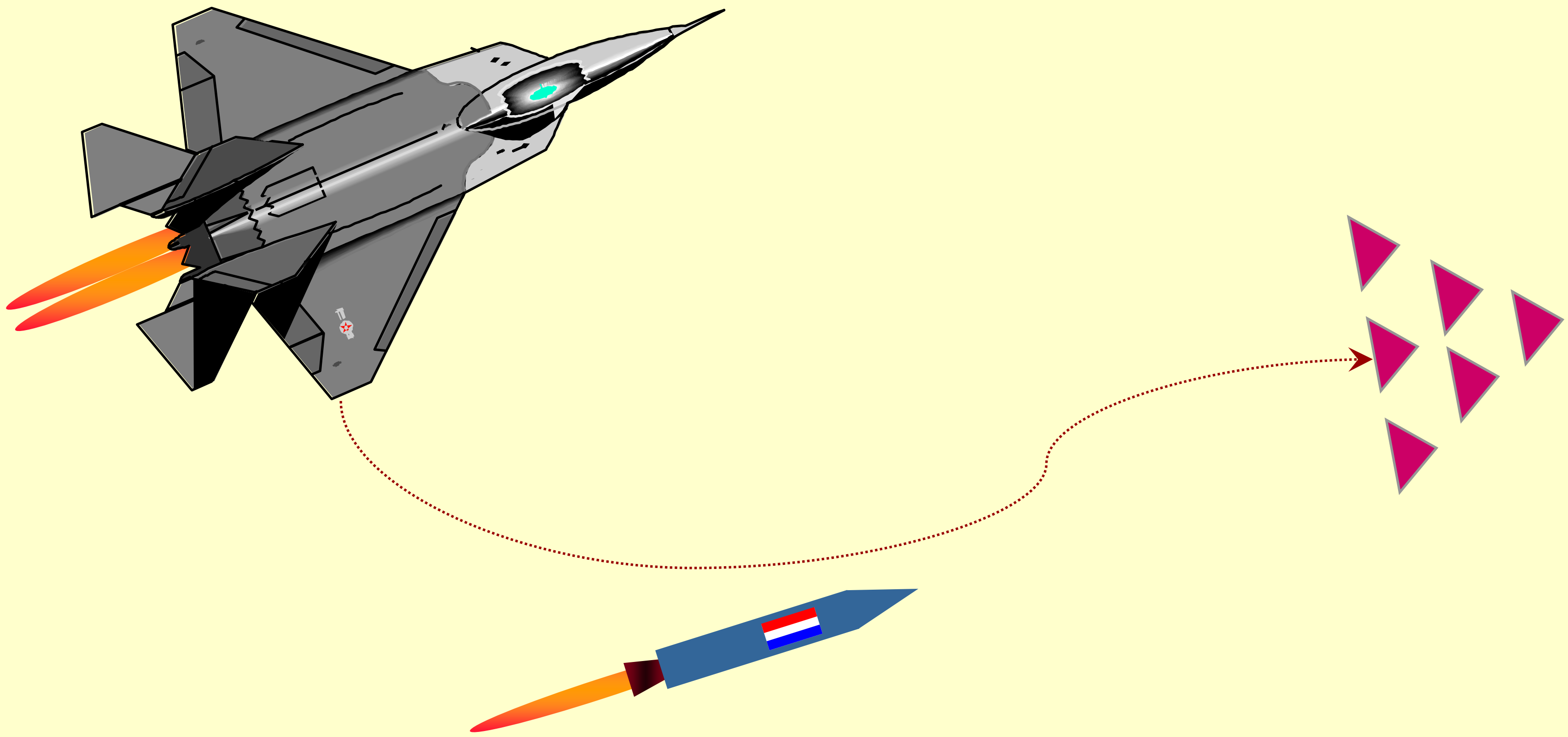


If you can’t see it, you can’t track it. If you can’t track it, you ain't gonna hit it!

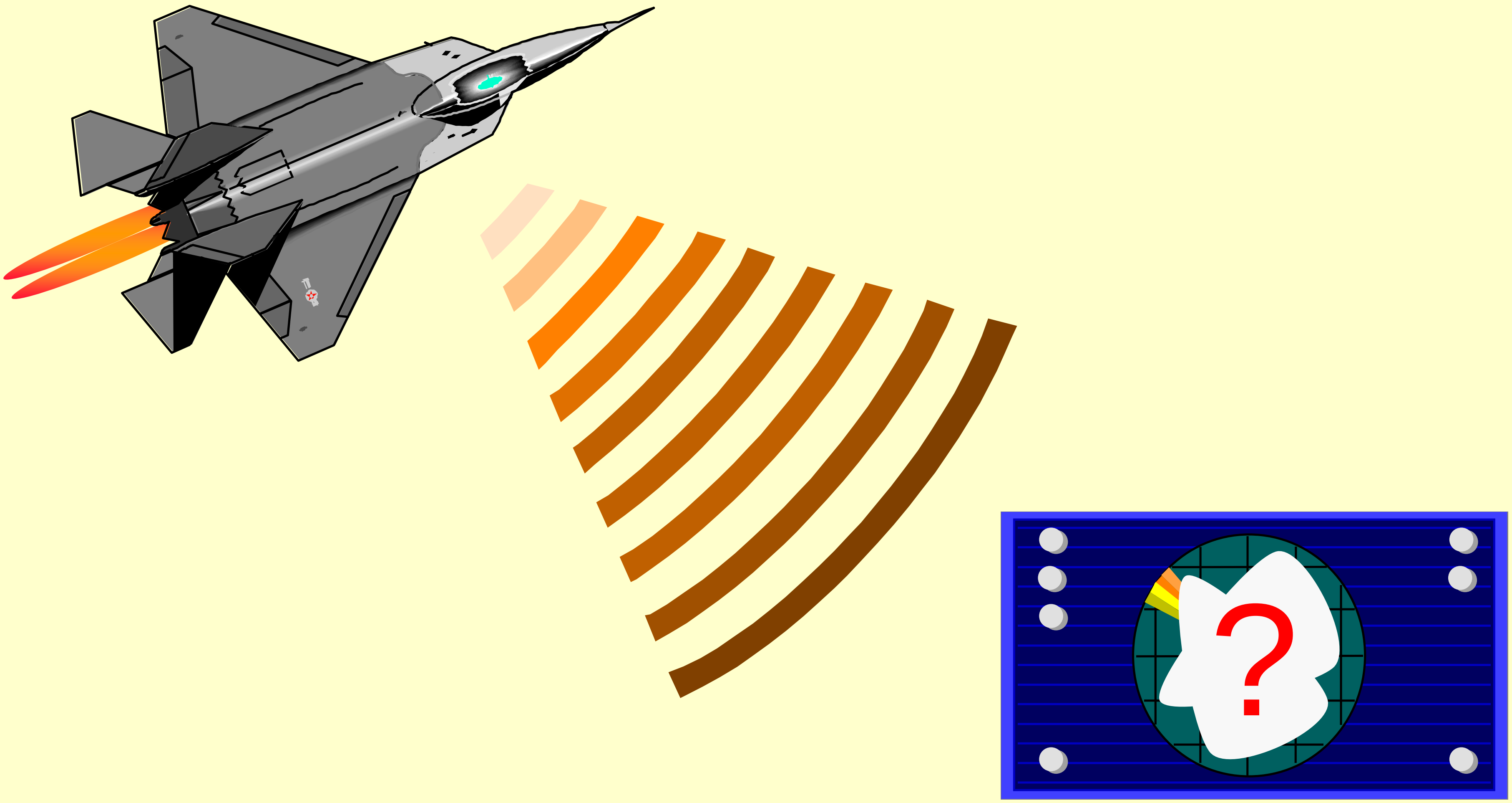
An Example of Modern Stealth Technology

Lockheed F-117A "Nighthawk"

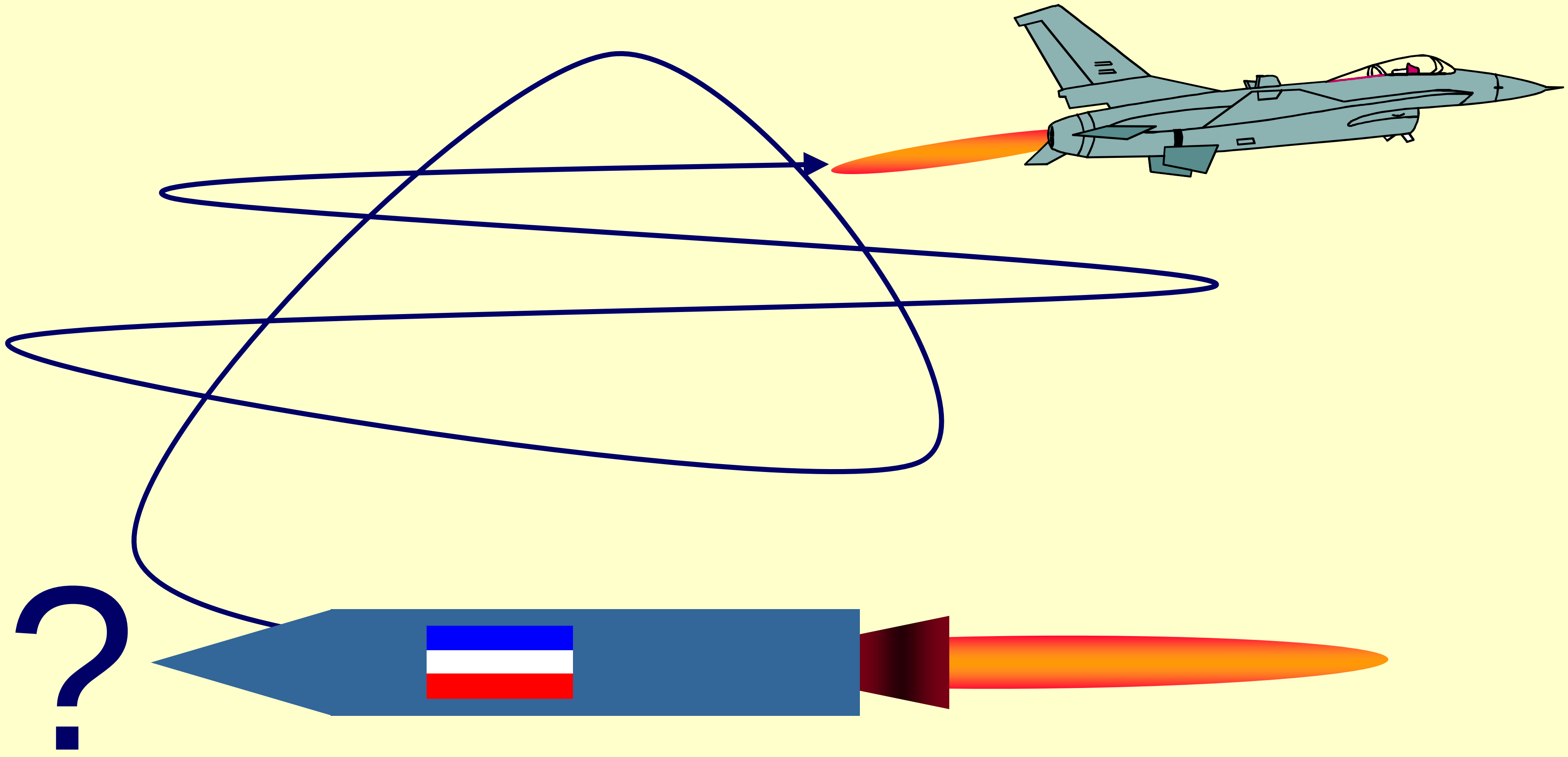
Reducing P_H by Decoys



Reducing P_H by Jamming

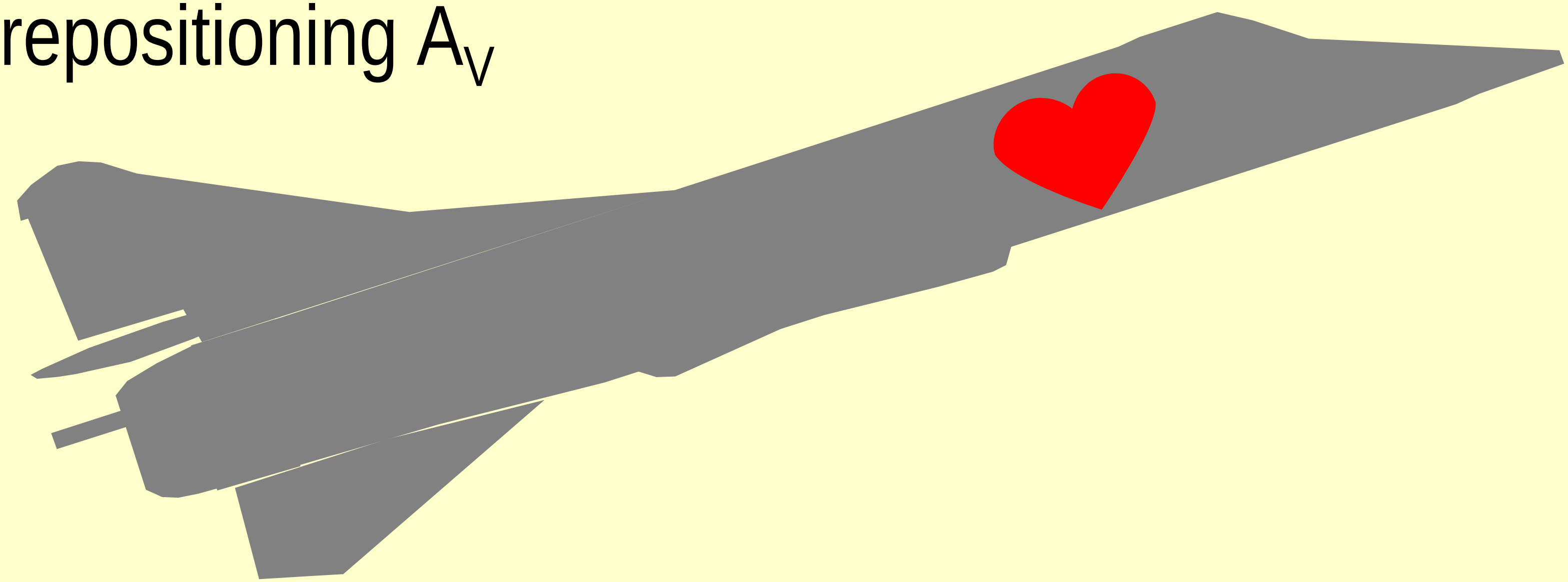


Reducing P_H by High Maneuverability

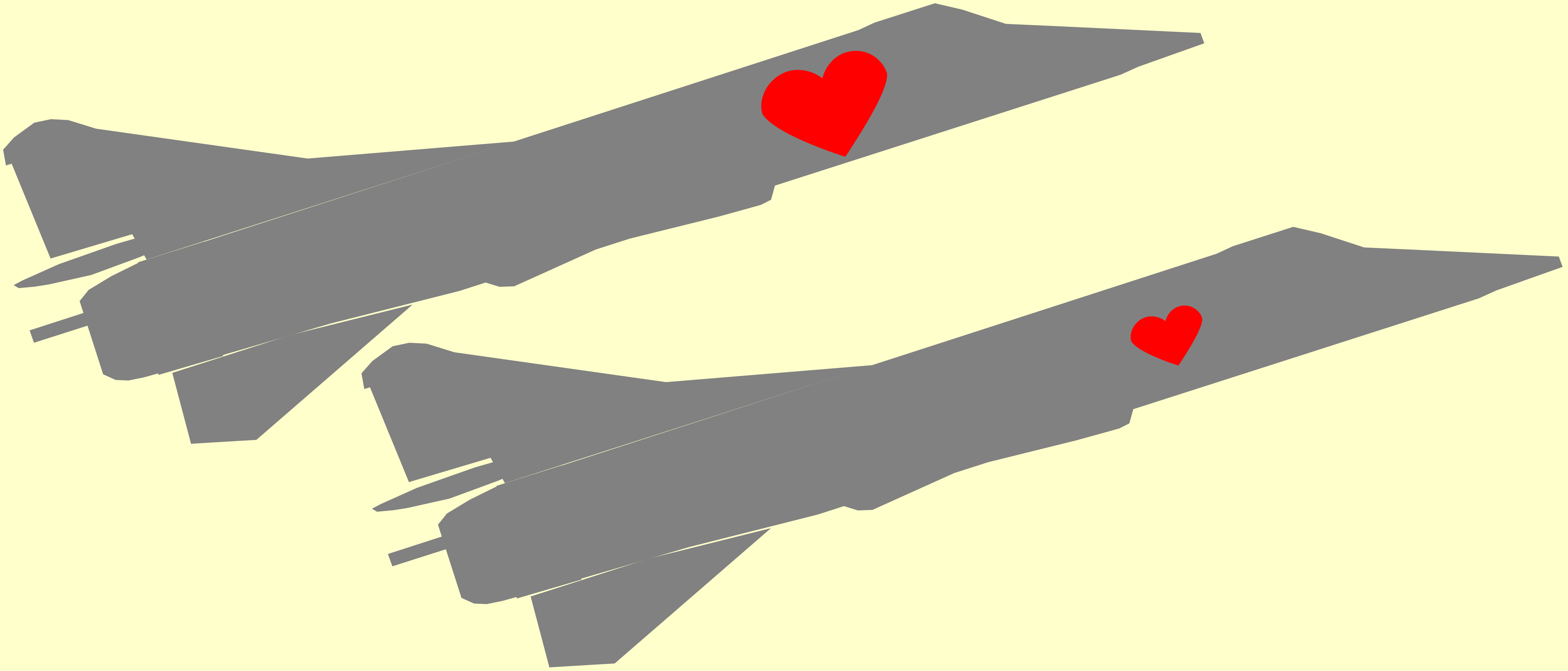


A_V/A_T is Reduced by the Following Methods

- By reducing the size of A_V
- By repositioning A_V

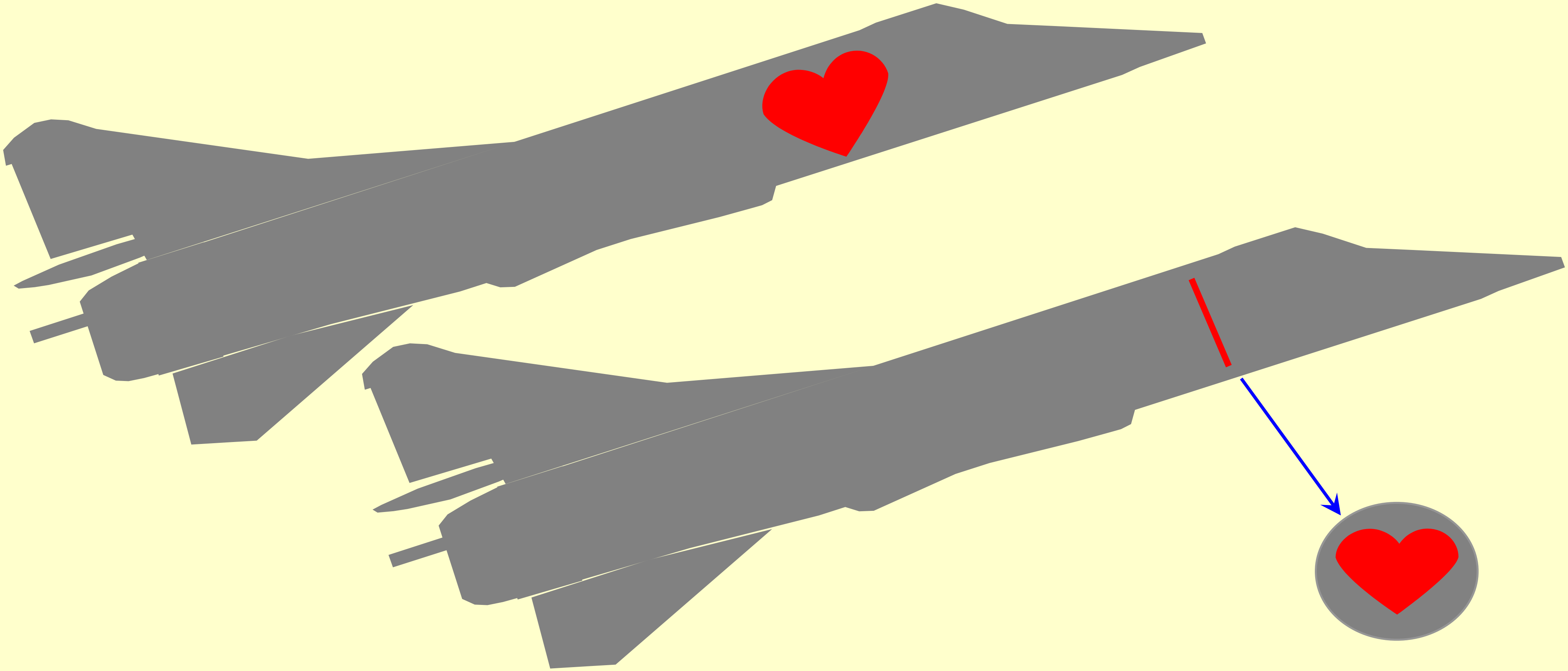


Reducing A_V/A_T by Decreasing A_v



This technique is called component miniaturization

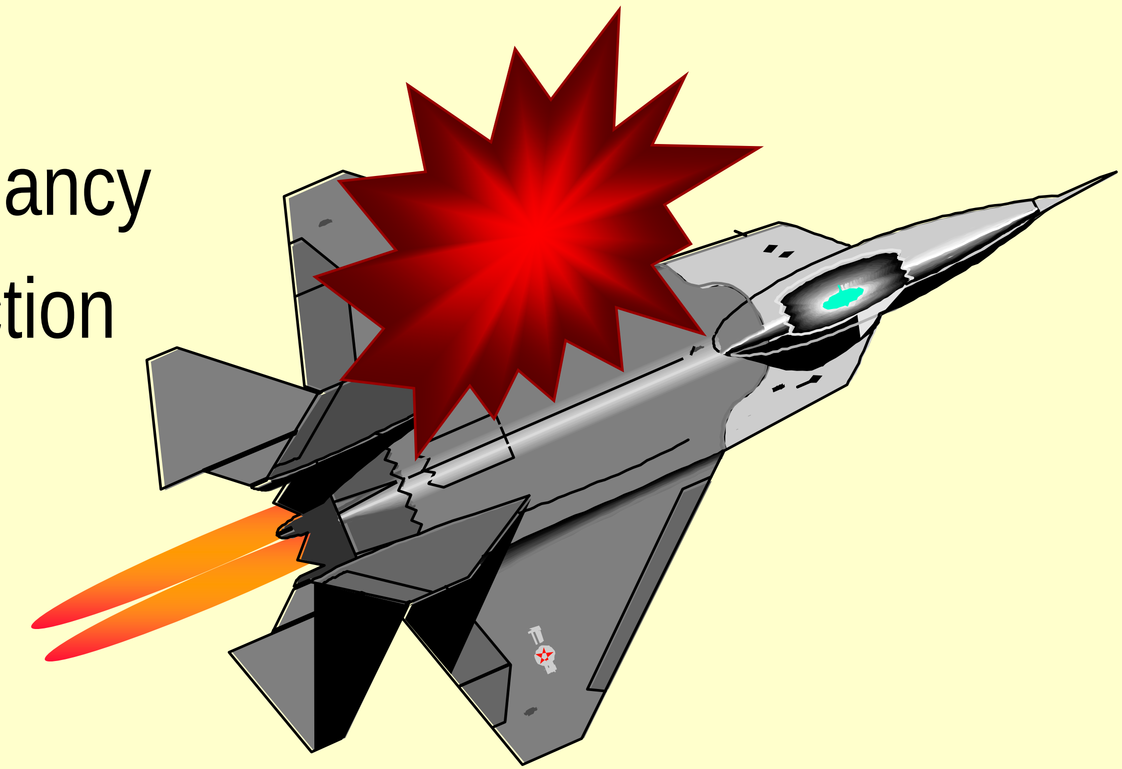
Reducing A_V/A_T by Repositioning A_v



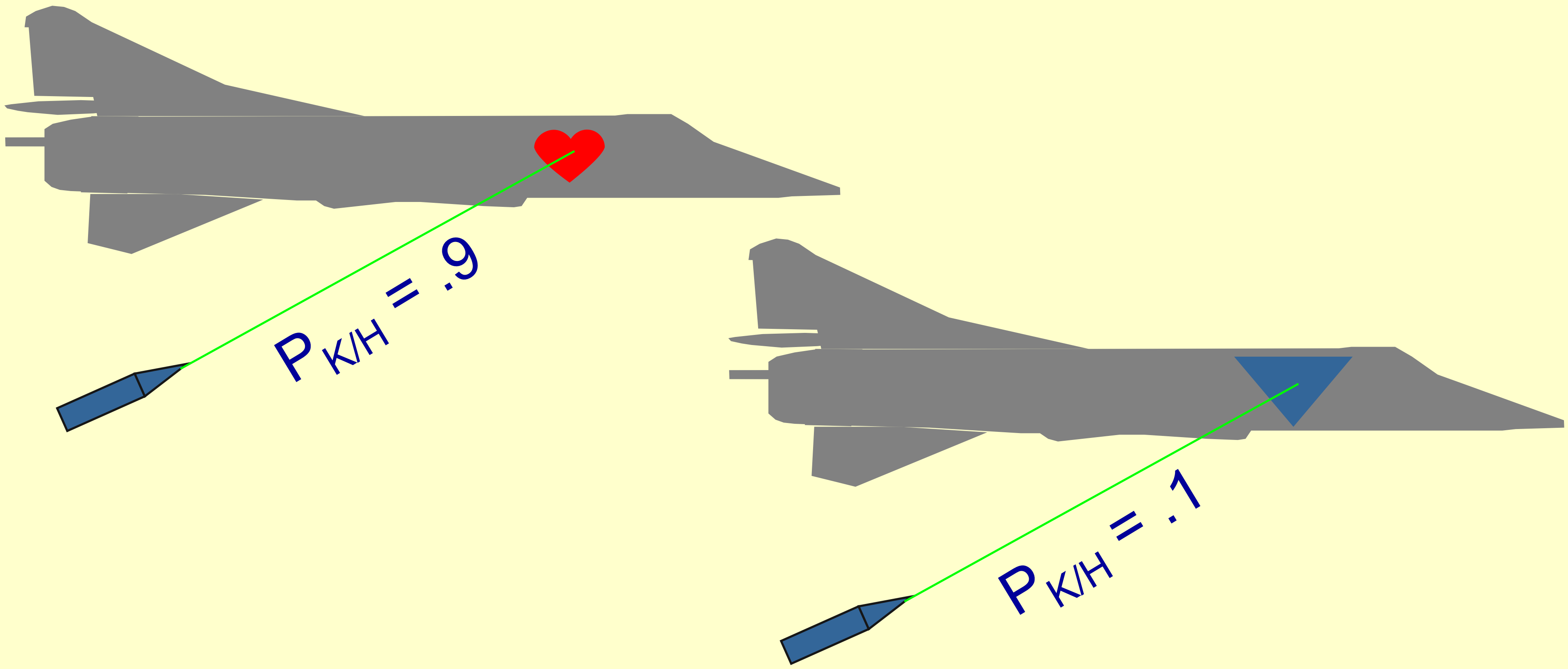
This technique is called component "cloaking"

$P_{K/H}$ is Reduced by The Following Methods

- By employing armor
- By passive shielding
- By subsystem redundancy
- By fuel-system protection



Reducing $P_{K/H}$ by Armor

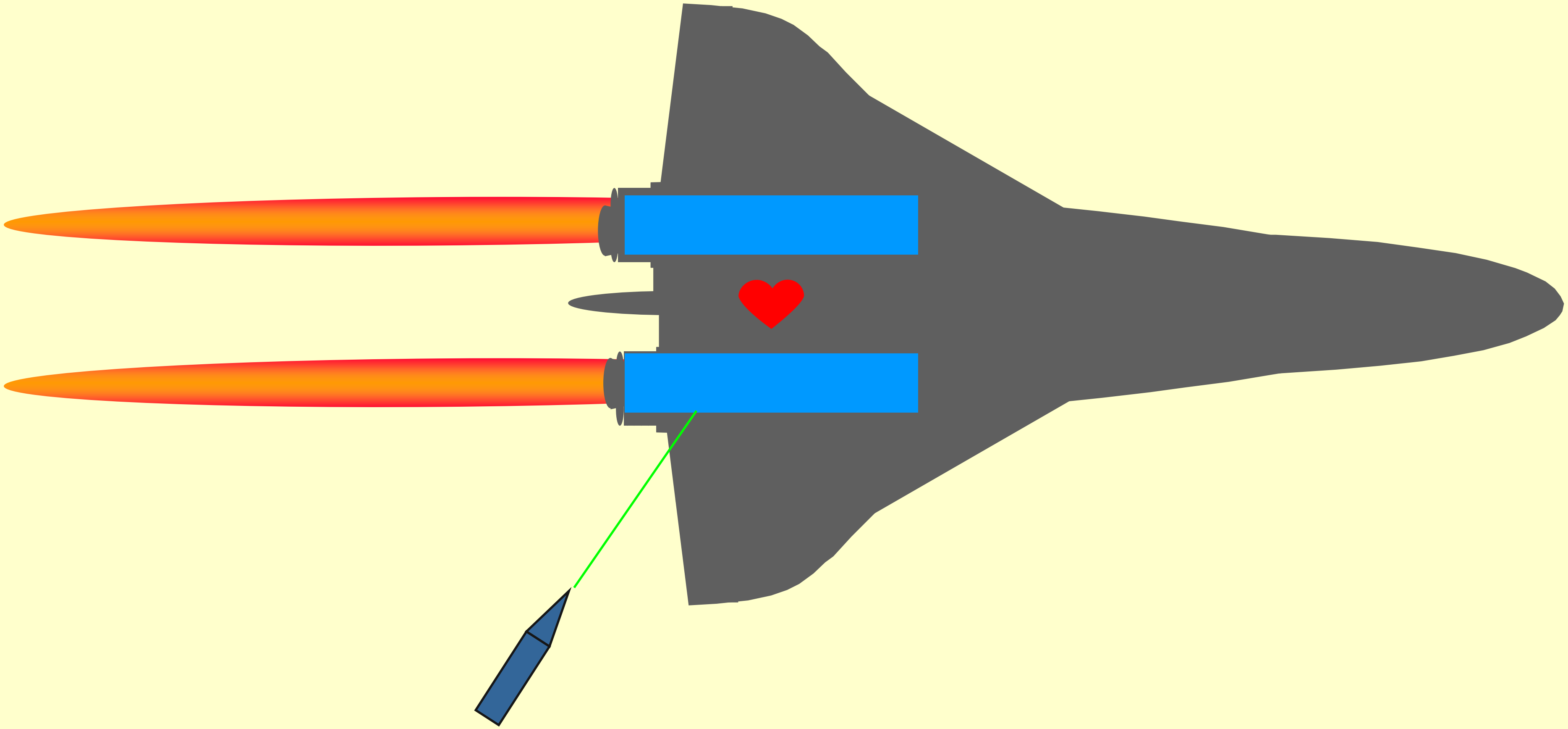


Armor is placed between the threat and vulnerable component.
Armor, if used, is only good for threats up to a certain size.

The A-10 Uses Armor to Protect the Pilot

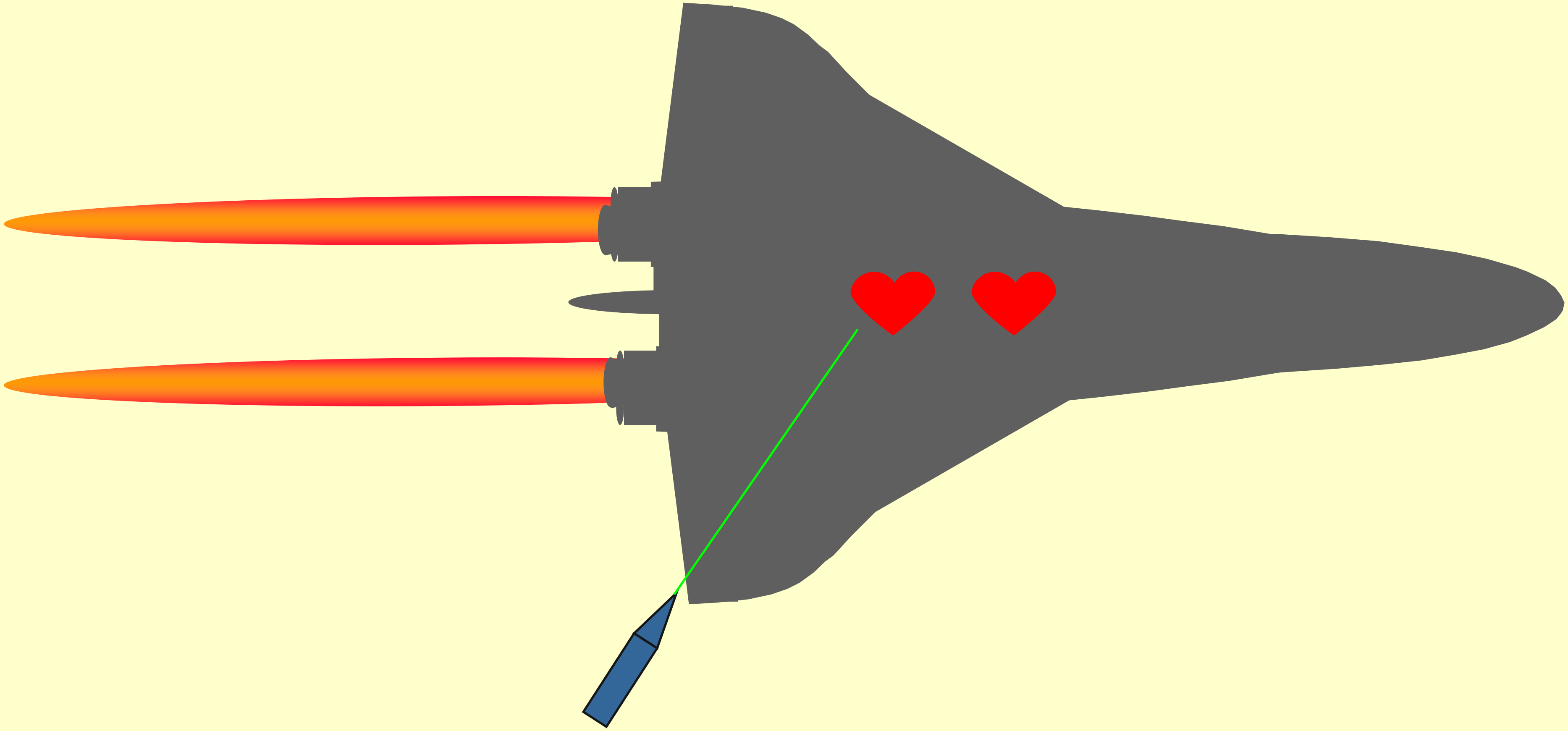
The pilot quite literally sits in a titanium bathtub.

Reducing $P_{K/H}$ by Passive Shielding



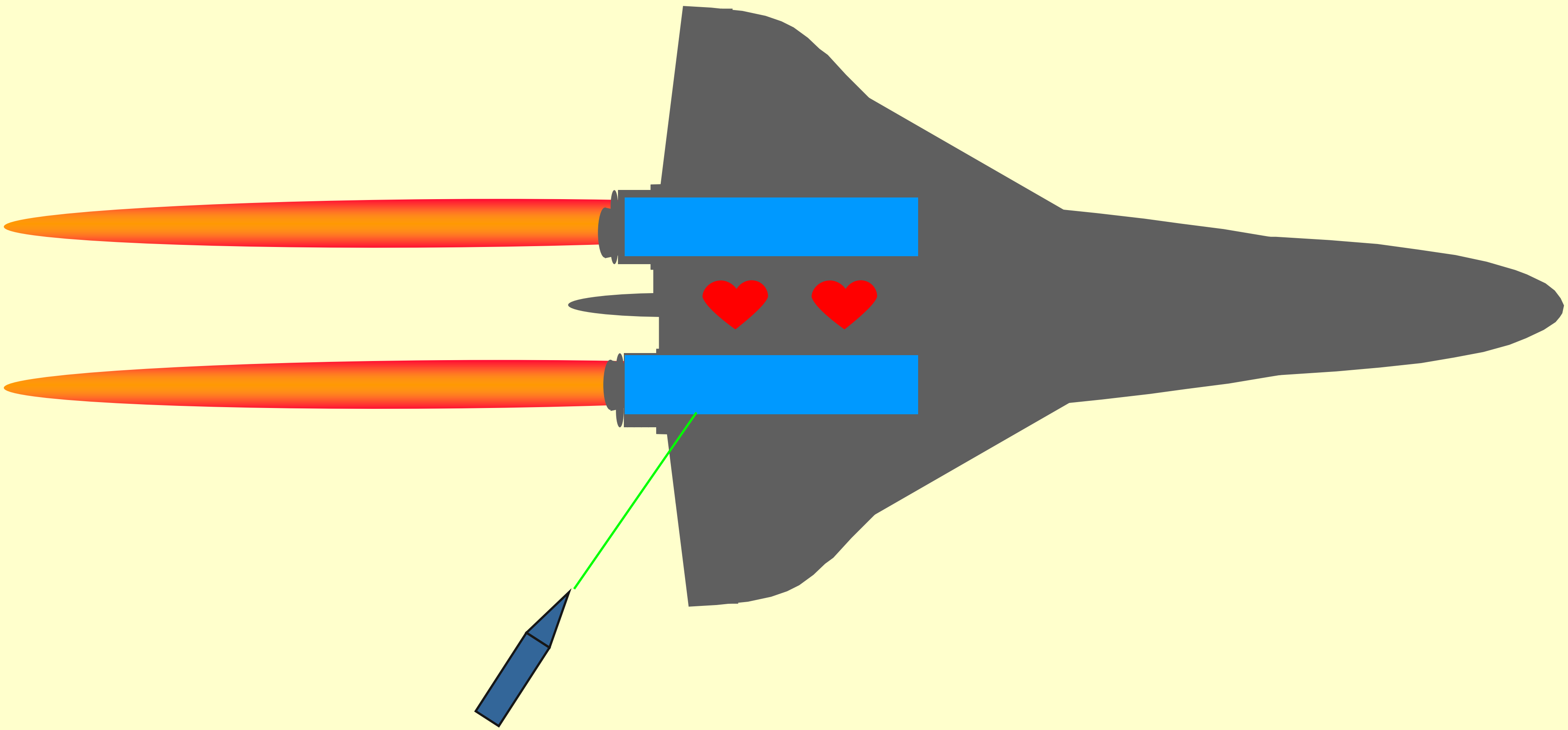
The vulnerable component is being protected by another component pulling double duty as “armor”.

Reducing $P_{K/H}$ by Subsystem Redundancy



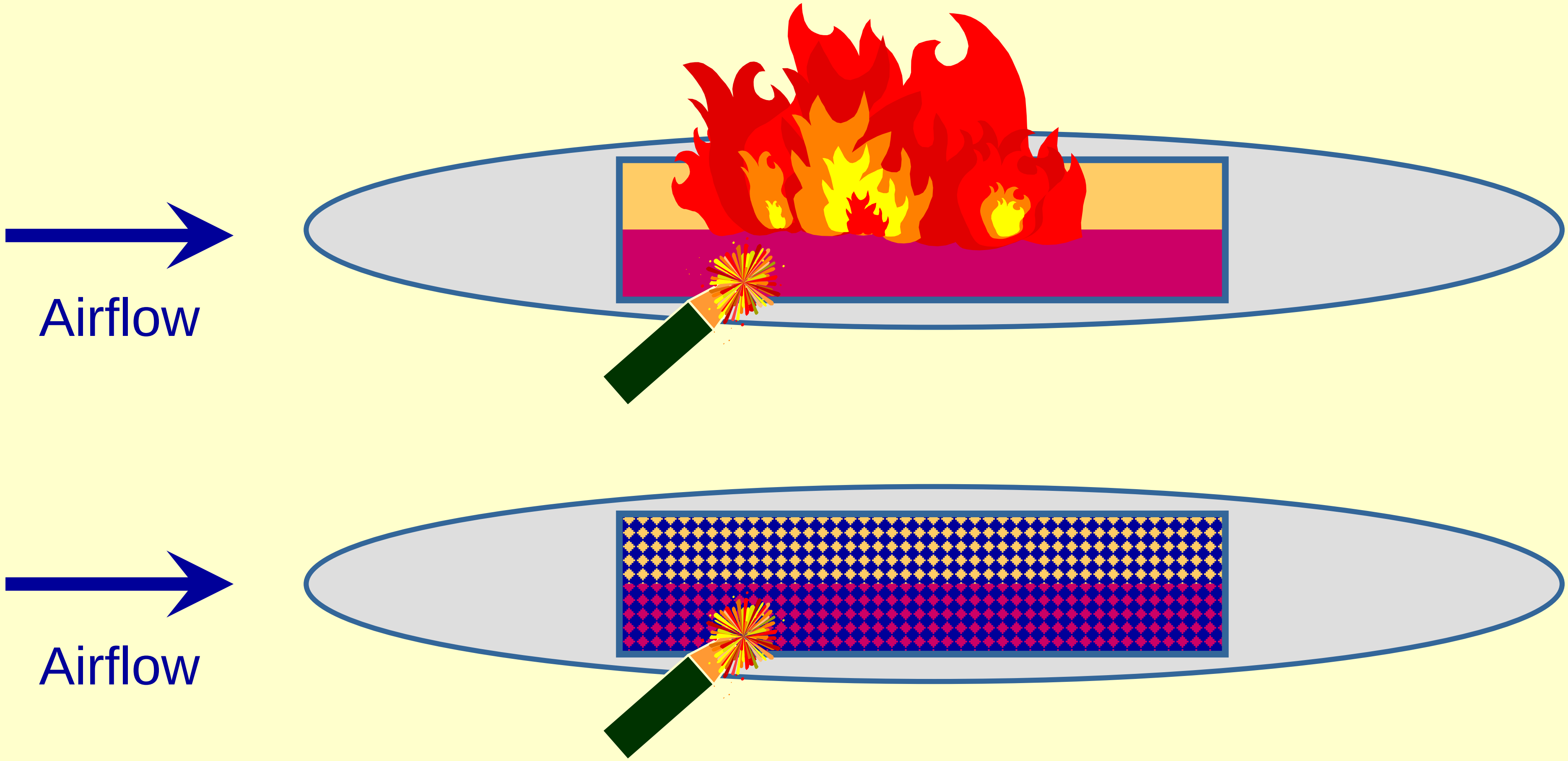
Let $P_{K/H}$ = .5 for the single vulnerable component. Cloning this component will lower the overall $P_{K/H}$ to (.5)(.5) = .25

Reducing $P_{K/H}$ by Both Shielding and Redundancy



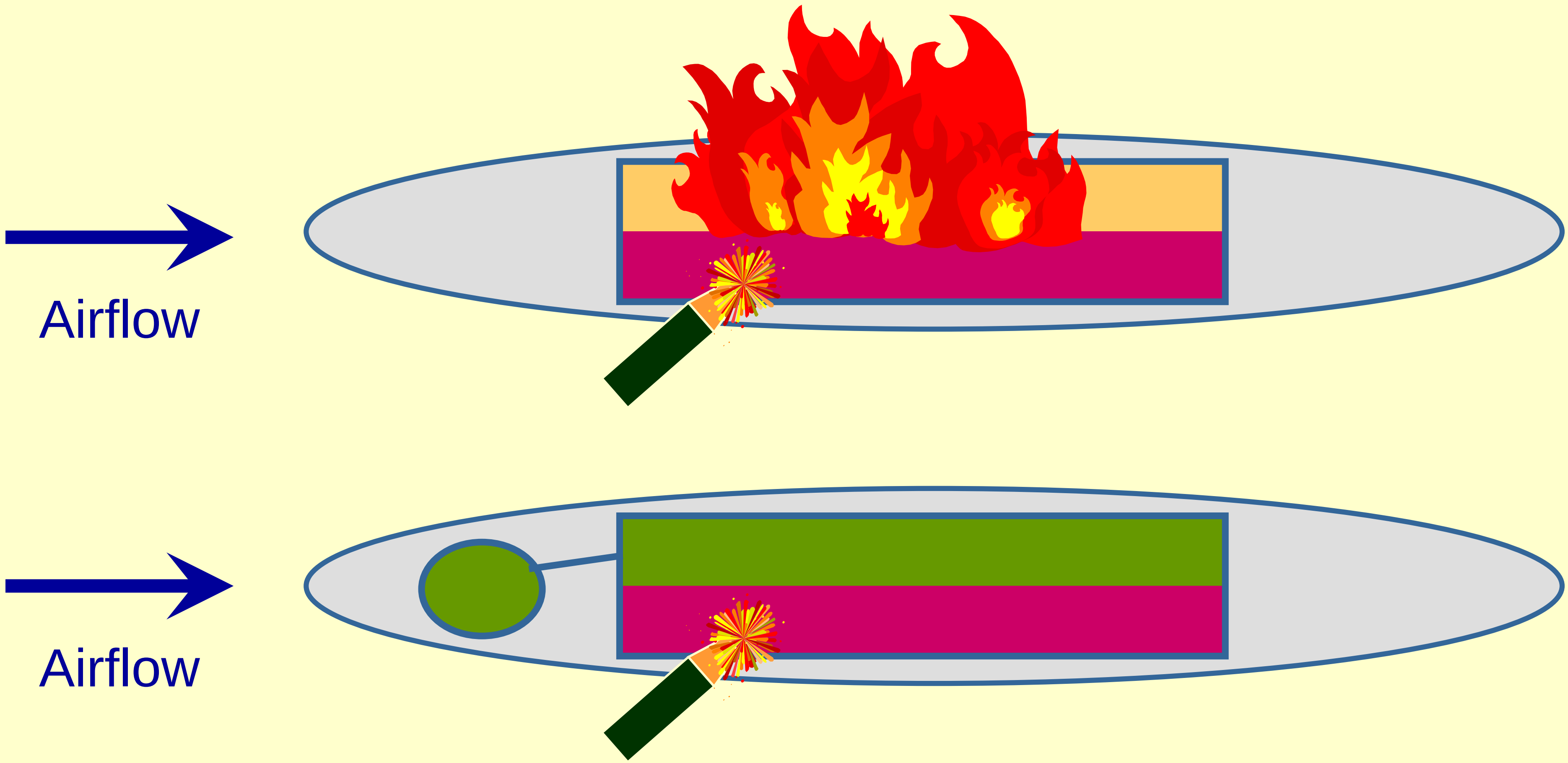
Sometimes we can "double protect" without a significant increase in weight penalty which is a real win!

Reducing $P_{K/H}$ by Fuel System Protection (1)



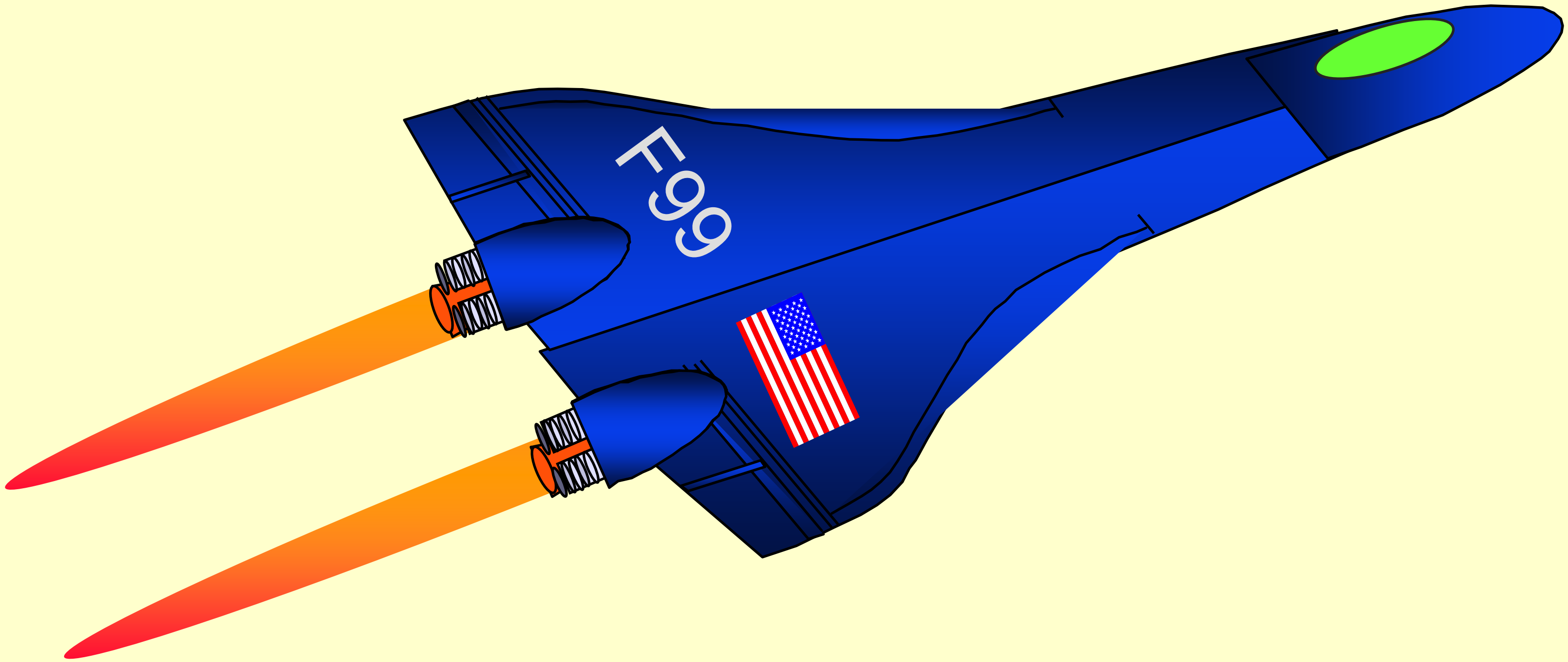
Foam system used in the F-4

Reducing $P_{K/H}$ by Fuel System Protection (2)



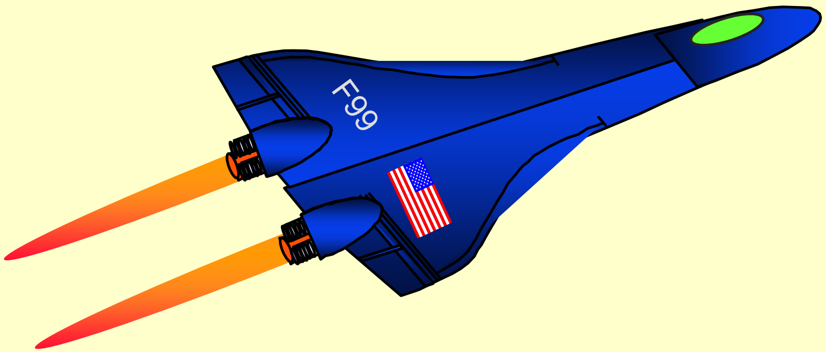
A modern fuel-tank protection system will displace the highly combustible ullage with a inert gas

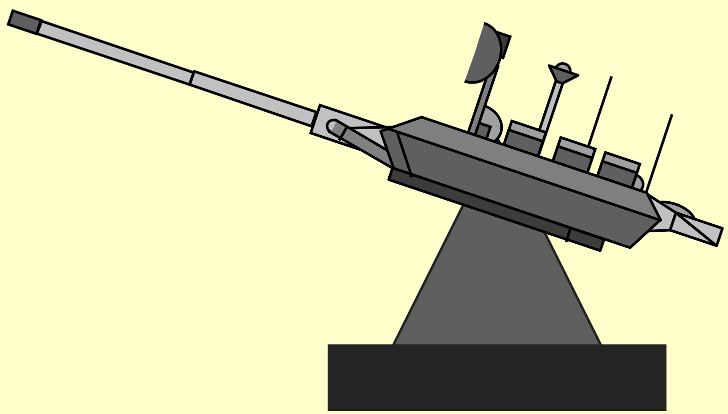
A True-to-Life Problem that Uses Probability



Meet the F99, a top-of-the-line American fighter!

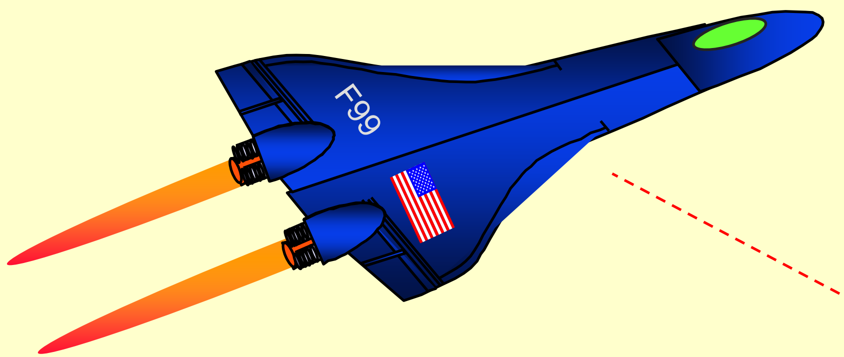
And Meet the Gun that the F99 is About to Take on...



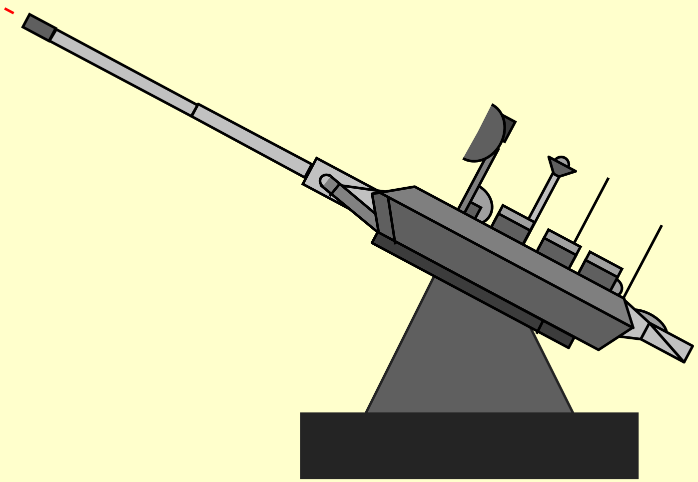


The Deadly K00!

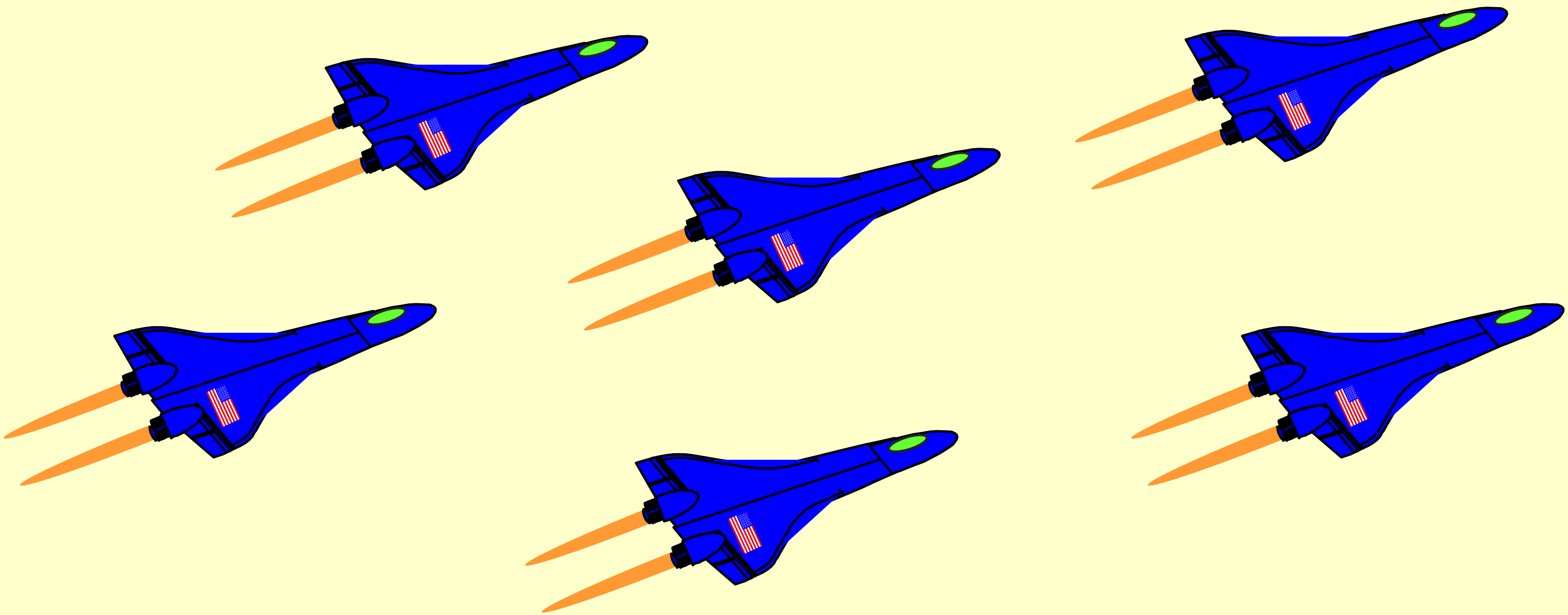
Facts About this Brutal Engagement



- P_H = .1 when facing the K00
- A_T = 200 ft^2
- A_V = 40 ft^2
- $P_{K/H}$ = .5 for A_V
- $P_{K/H}$ = .05 for A_T - A_V



The Scenario



The Air Force plans to send a first-wave strike force consisting of 1000 F99s into glorious battle against the K00.

The Science of Survivability: Counting the Costs!

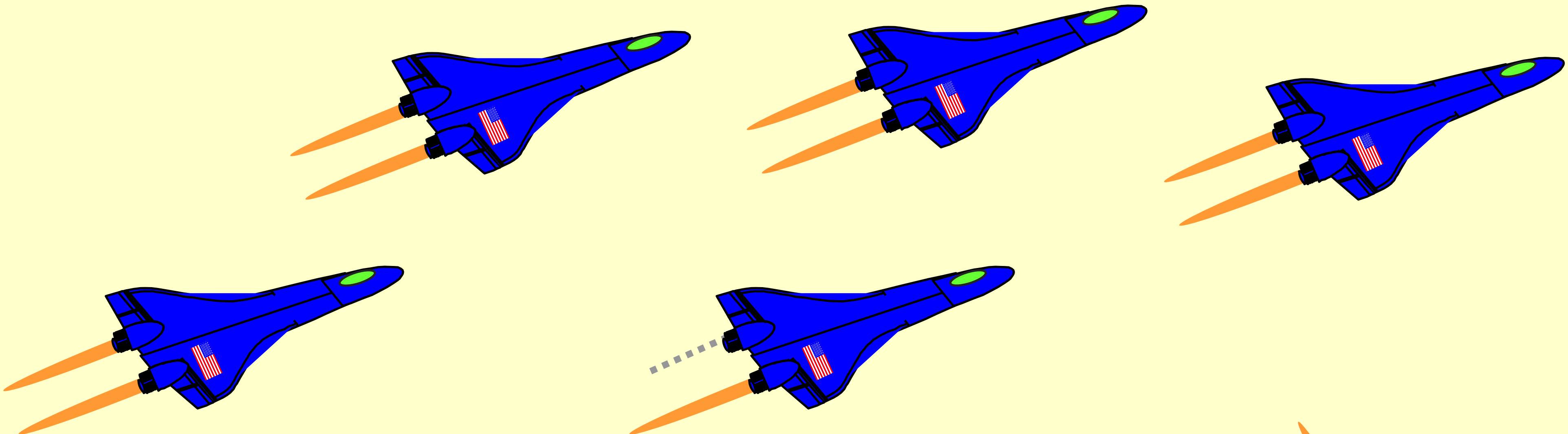
- How many aircraft are expected to return home without a scratch?
- How many aircraft are expected to return home damaged?
- How many aircraft are expected to go down in flames over enemy territory?

Assume that killed aircraft never return and damaged aircraft will always return.

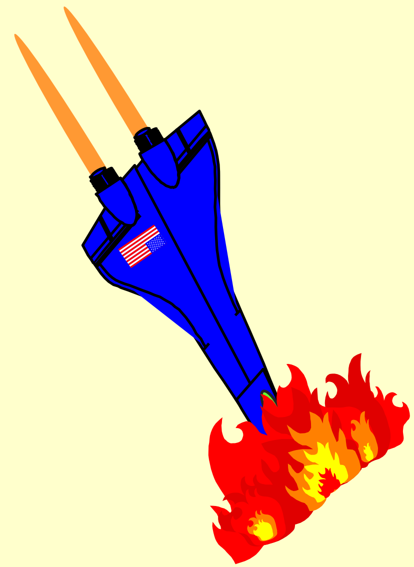
Hints in Working the Aircraft Survivability Problem

- Use a probability tree diagram to obtain all possible engagement scenarios
- Assign a probability to each engagement scenario using the given data
  - Use your basic probability rules
- Use the concept of expected value
- Discuss your approach before solving the problem!
  - With other students
  - With your teacher

Answers



- 900 F99s will return without a scratch
- 86 F99s will return damaged
- 14 F99s will be killed



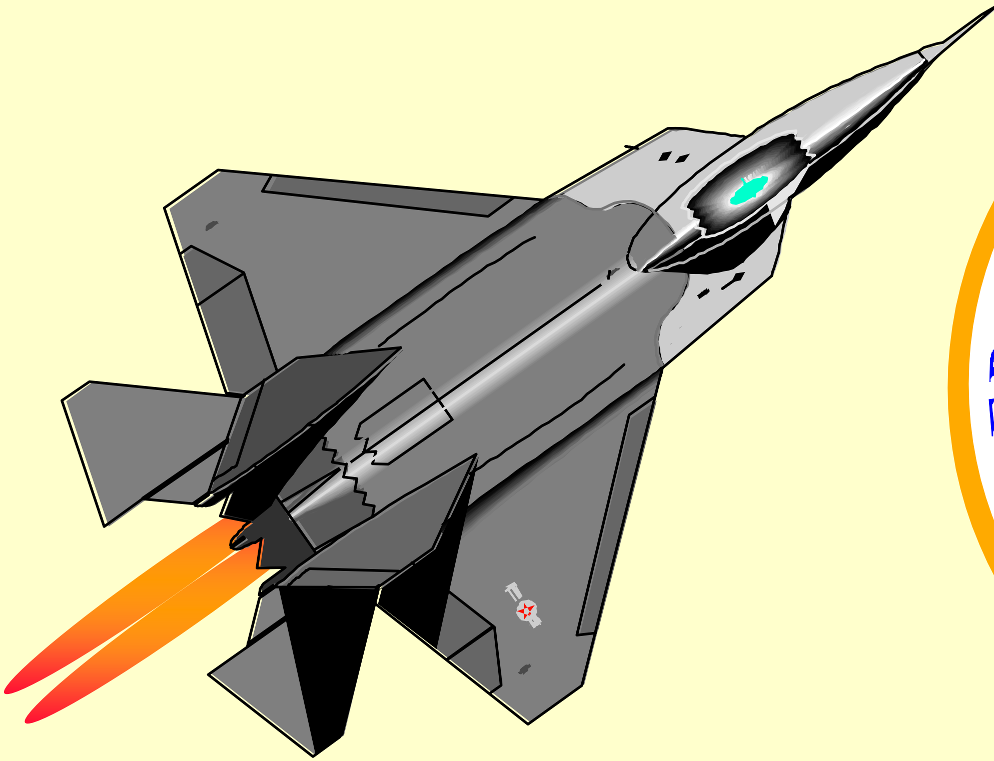
A Question for Group Discussion

If you were an engineering manager and wanted to improve the performance of the F99 against the K00, where would you get the most “bang for the buck”, reducing P_H or $P_{K/H}$? How does this answer relate to what actually happened over those Serbian skies in 1999?

To Summarize

Aircraft survivability is the science of protecting an aircraft during peacetime and in war. Aircraft survivability is a multidisciplinary science which combines elements of engineering, testing, probability, and statistics.

And the United States Air Force is...



An Expert in this Discipline!!