Miserable Risk Estimation:

"Managing" Low-Probability, High-Consequence Risks

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All Grand Enterprises Must Define Their Risks
(Including High-Consequences, Low-Probability Risks)

Defining the High-Consequence Part of Risks is Comparatively Straightforward:

- NASA Mishap Investigations
- Military Incident Levels
- “Everybody dies.” – C. Null

Defining the Low-Probability (Especially Very-Low-Probability) Part of Risks is More Fraught:

- Tongue-in-Check Methodology
- NASA (“Management Science”) Methodology

Defining Low-Probability, High-Consequence Airline Risks… A Tongue-In-Cheek Approach:

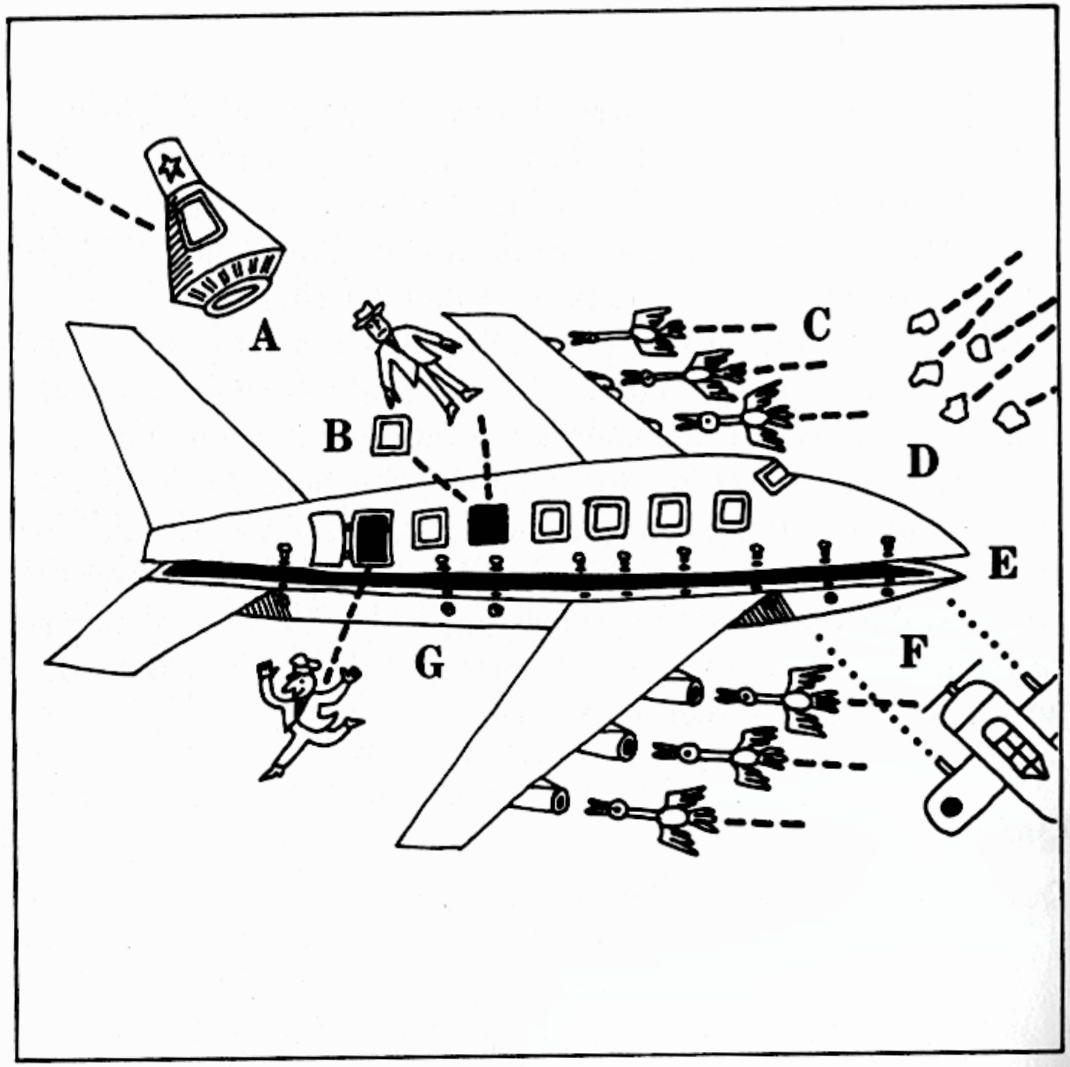


FIG. VIII: POSSIBILITIES TO CONSIDER WHILE FLYING

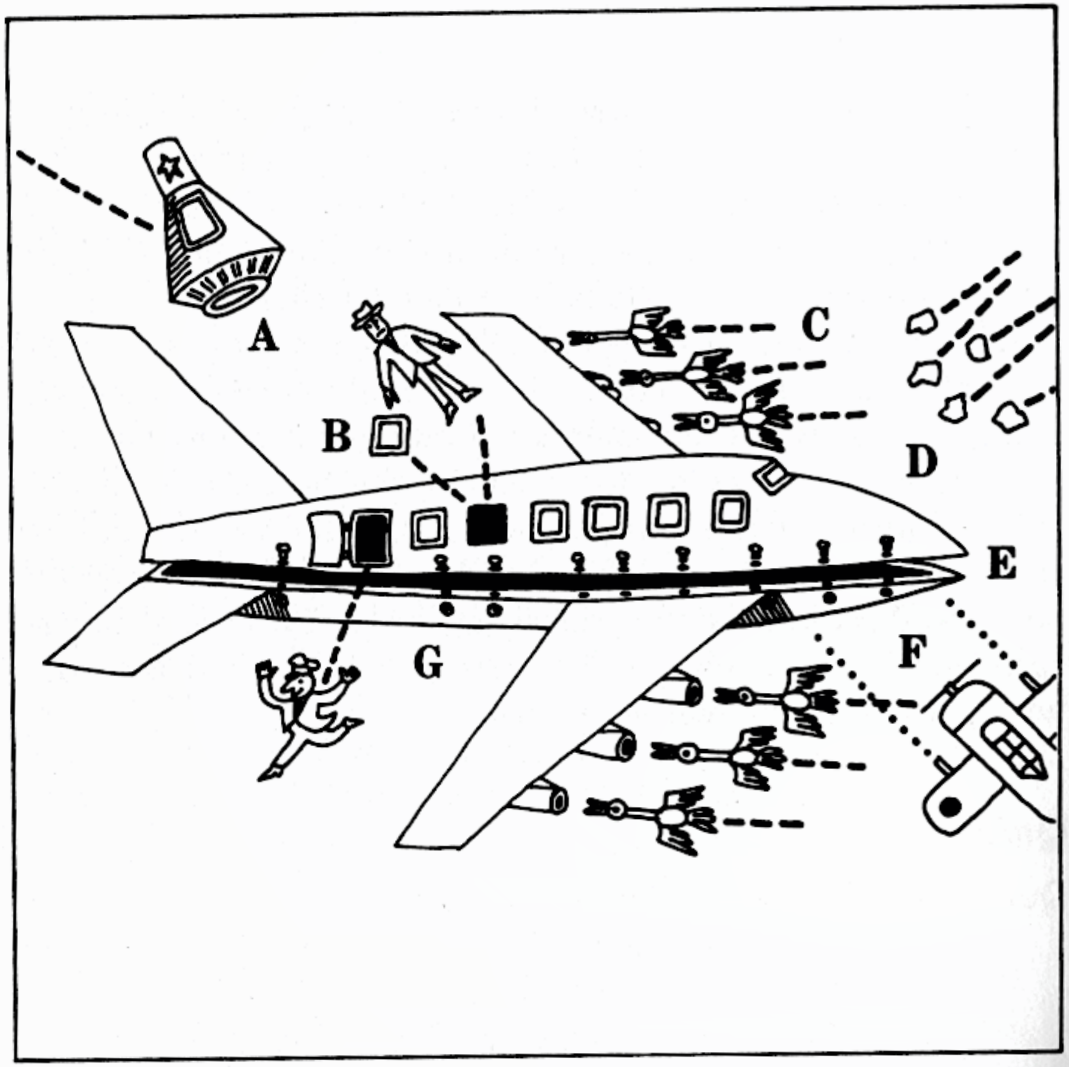
(A) Re-entering space capsule could collide with plane; (B) poorly sealed window could pop out, sucking you through opening; (C) six wild geese could simultaneously enter and clog jets; (D) sudden meteorite shower could puncture fuselage; (E) excessive vibration could loosen bolts holding top and bottom halves of plane together; (F) plane could be shot down by die-hard WW II kamikaze pilot; (G) disturbed pilot could leap from plane in fit of pique.

Seven risks to worry about from: “How to Make Yourself Miserable (for the Rest of the Century): A Vital Training Manual” by Dan Greenburg with Marcia Jacobs, Vintage Books, 1966

Actual Miserable Accidents

A or D. Maybe…

(Visualize a B-757 with its Radome [nose] punched in.)



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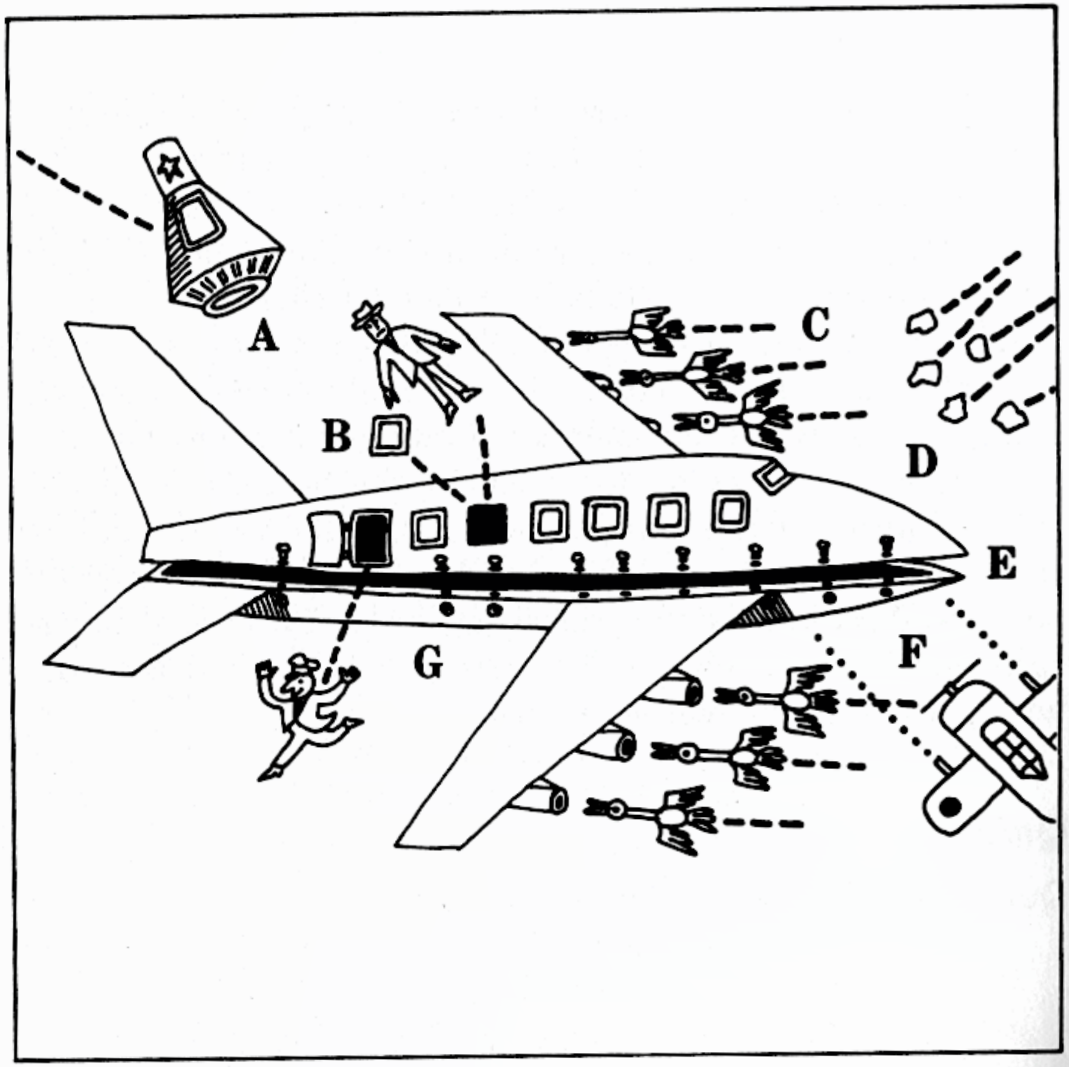
June 4, 2013: An Air China Boeing 757-200 collided with an unknown object while climbing through FL260 (26,000'), resulting in evident damage to its radome.

-- Space Safety Magazine Press Clip, June 20, 2103 (Credits: The Aviation Herald)



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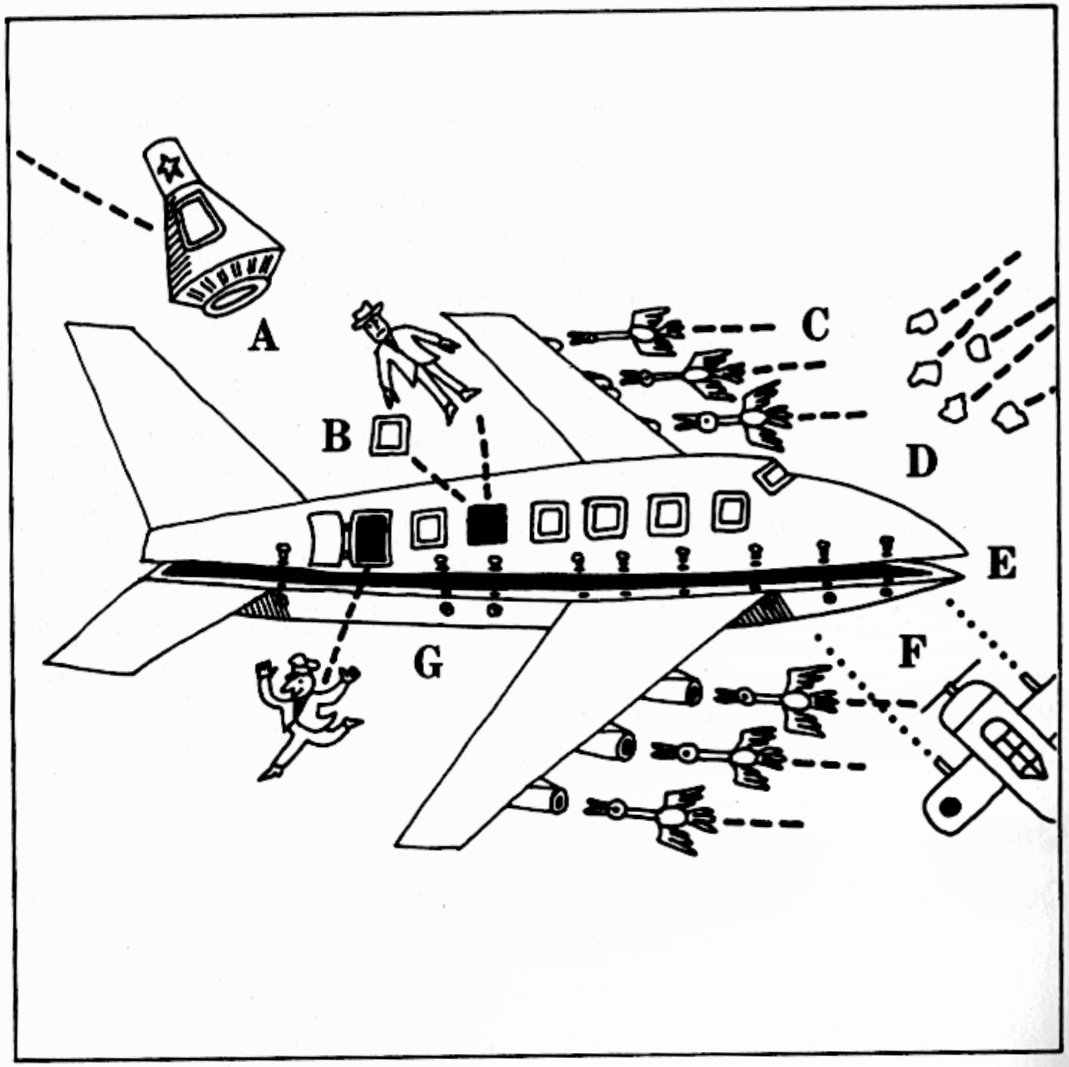
B. Technically, not all the way out, and it wasn't a sealant failure…

(Visualize side-by-side pictures of Ms. Riordan and the broken-out window.)

April 17, 2018: Shrapnel resulting from an engine's fractured fan blade of a Southwest Boeing 737-700 damaged the fuselage and window near passenger Jennifer Riordan. Despite wearing her seat belt, she was partially blown out of the plane and died from blunt impact trauma.

-- The Straits Times, April 19, 2018 (https://www.straitstimes.com/world/united-states/from-her-waist-above-she-was-outside-of-the-plane-passengers-describe-southwest ; Credits: The United Way of Central New Mexico, Facebook/Marty Martinez)



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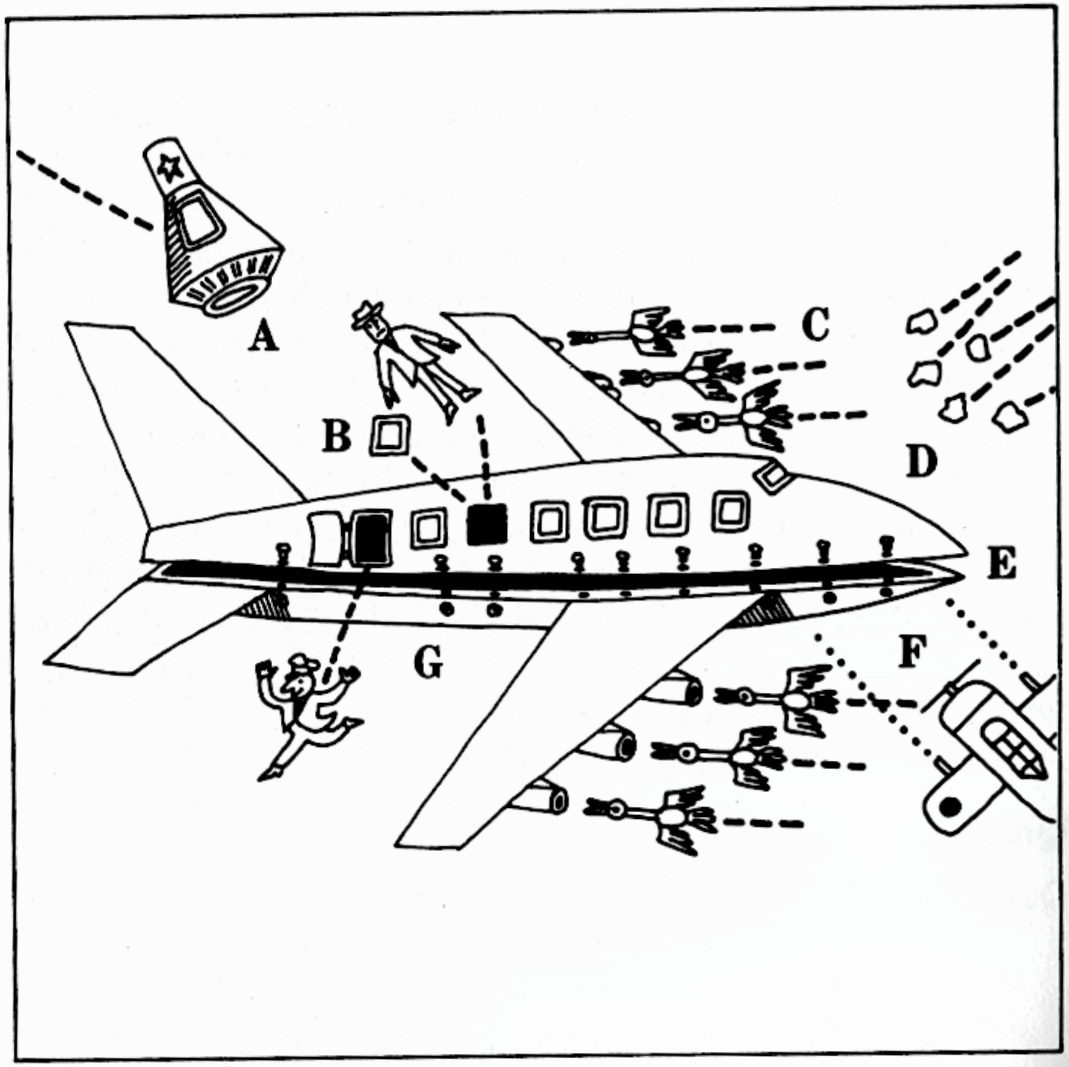
C. The exact number of geese is unknown, but they only had to take out TWO engines…

January 15, 2009: US Airways Flight 1549 (an Airbus A320-214) struck a flock of geese while climbing through an altitude of 2800'. Both engines shut down, forcing an emergency landing in the Hudson River performed by Captain Chesley "Sully" Sullenberger (Tom Hanks) and First Officer Jeffrey B. Skiles

Ng, G. L. (n.d.). Plane crash into Hudson River [Photograph]. CC BY 2.0



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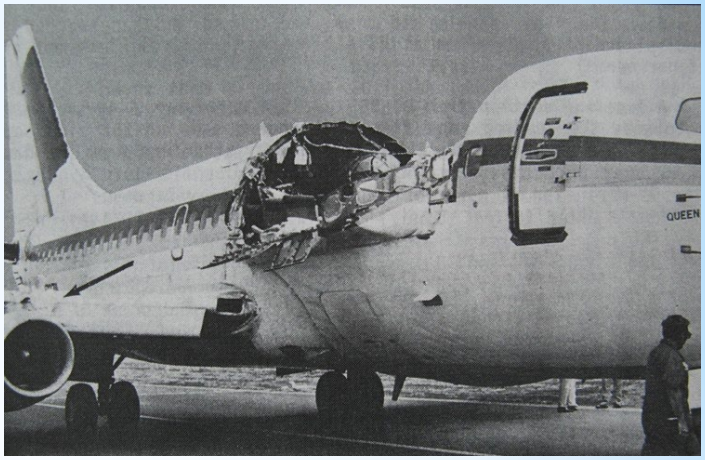
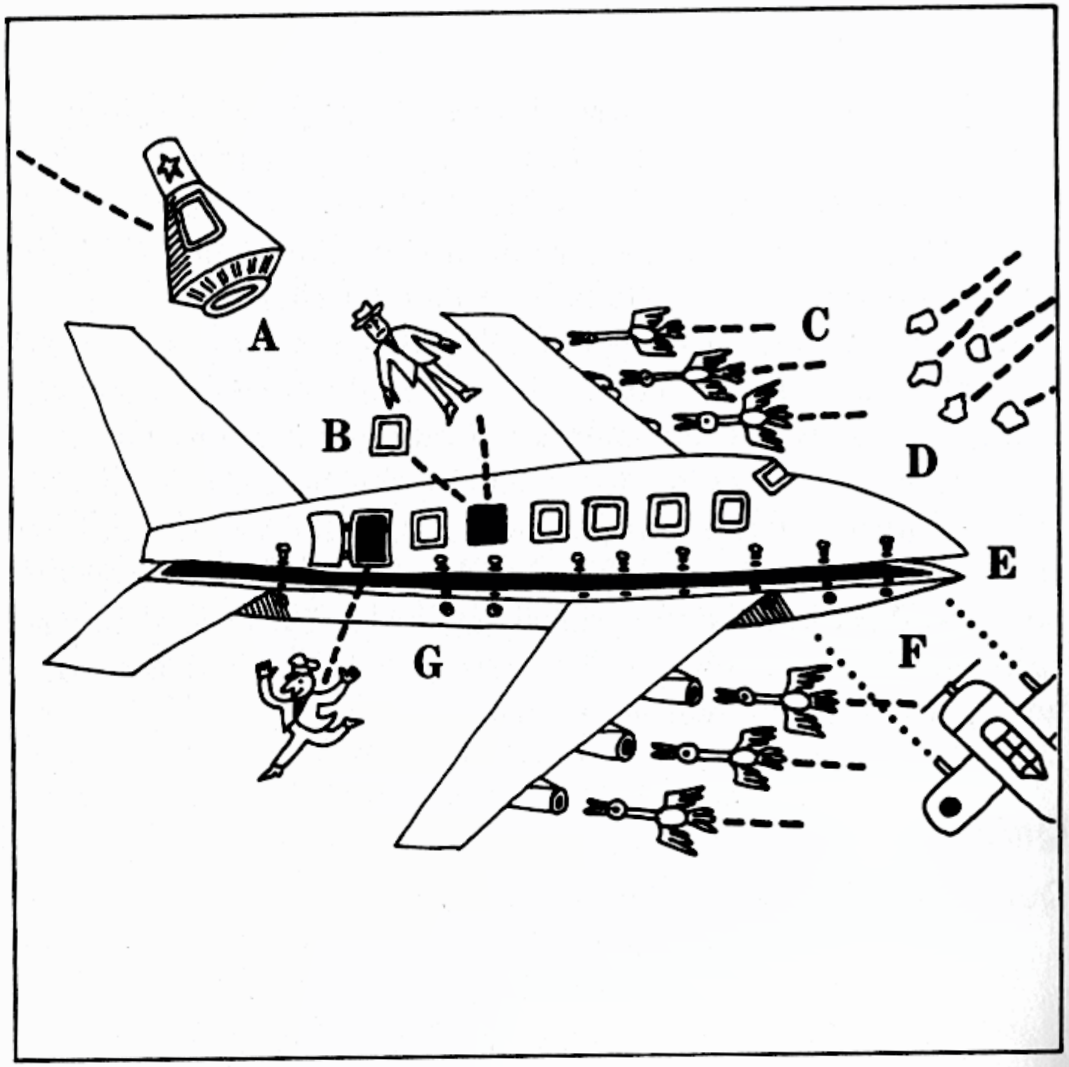
E. Does the fuselage peeling apart count?…



April 28, 1988: Aloha Airlines Flight 243 (a Boeing 737-297) suffered an explosive decompression resulting from metal fatigue exacerbated by crevice corrosion. The aircraft had operated for 19 years in a coastal environment, and had logged nearly 90,000 flight cycles (takeoffs and landings).

-- Wikipedia, Accessed 4/18/20 (https://en.wikipedia.org/wiki/Aloha_Airlines_Flight_243#/media/File:Aloha_Airlines_Flight_243_fuselage.png)
-- Image Source (public domain): (http://aviation-safety.net/photos/displayphoto.php?id=19880428-0&vnr=2&kind=C)



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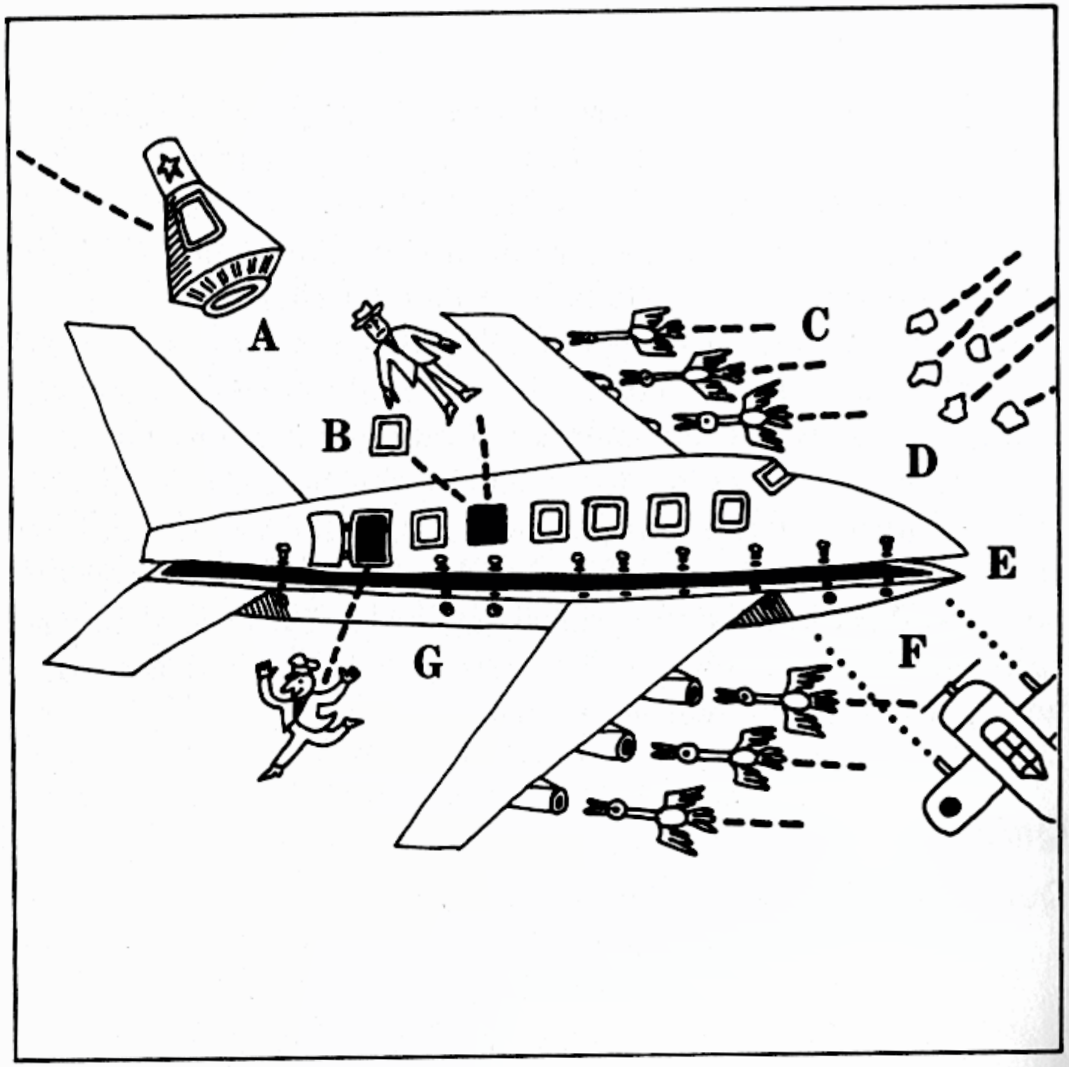
F. Not a die-hard WWII Kamikaze pilot, but…

…Well, this is too depressing. Starting with a failed assassination attempt in 1938 during the Second Sino-Japanese War (which WAS by performed by a Japanese aircraft), Wikipedia lists 38(!) “airliner shootdown incidents” – these include wartime incidents, but not terrorist bombings or sabotage.
So… REALLY not funny.



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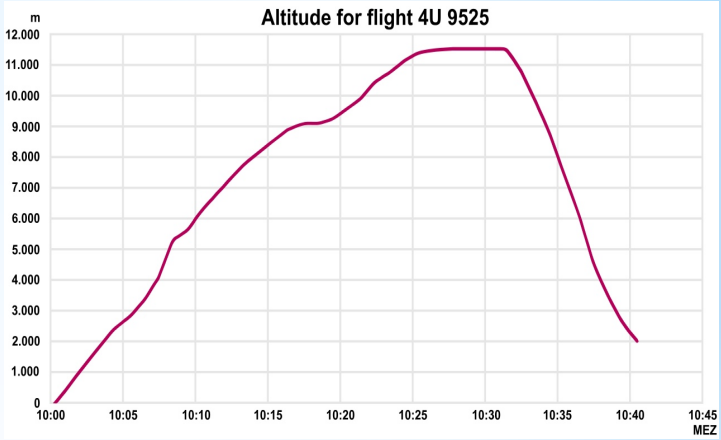
G. Pilot didn't actually leap from the airplane…



March 24, 2015: Germanwings Flight 9525 (an Airbus 1320-311) was intentionally crashed into the French Alps by Co-pilot Andreas Lubitz.
If you wish to make yourself more miserable, read the "Suicide by Pilot" wiki page, which lists a slew of declared or suspected pilot suicides.

-Lampel. (n.d.). *Altitude for flight 4U 9525* [Graph]. https://commons.wikimedia.org/wiki/File:Altitude_Chart_for_Flight_4U9525_register_D-AIPX.png

A "Management Science" Approach to Risk Management: The L x C Table

- Risk Severity is defined as a function of the Likelihood of the event and the Consequence of its occurrence.
- Many hours were billed in determining the correct number of squares, their proper color, and which axis is which.

The Granddaddy: 5 x 5; Five Color

Table 14: Risk Exposure Matrix

Impact \ Probability	Rare (1)	Remote (2)	Occasional (3)	Probable (4)	Frequent (5)
Maximum (5)	Medium (3)	Medium (3)	High (4)	Maximum (5)	Maximum (5)
High (4)	Low (2)	Low (2)	Medium (3)	High (4)	Maximum (5)
Medium (3)	Minimal (1)	Low (2)	Low (2)	Medium (3)	High (4)
Low (2)	Minimal (1)	Minimal (1)	Minimal (1)	Low (2)	Medium (3)
Minimal (1)	Minimal (1)	Minimal (1)	Minimal (1)	Minimal (1)	Low (2)

From Alberts, Woody, & Dorofee (2014). Introduction to the Security Engineering Risk Analysis (SERA) Framework. Technical Note, CMU/SEI-20140TN-024, Carnegie Mellon University

Visualize* Many Pretty Matrices!

- 3 X 3, 4 X 4, 5 X 5!
- L X C, C X L, P X I, I X P!
- No consistency in transitions from Green to Yellow to Red
  - Maybe throw in Oranges and Blues
- Few definitions of levels of Probability/Likelihood!
- Little definition of resource allocation for Red vs. Yellow

*or Google “L x C Matrices” and click on “Images”

NASA Has Its Own Favorite(s)

ISS Program

Likelihood					
5	15	10	6	3	1
4	19	14	9	5	2
3	22	18	13	8	4
2	24	21	17	12	7
1	25	23	20	16	11
	1	2	3	4	5

Consequence

Commercial Crew Program

ESD Scorecard

LIKELIHOOD					
5	10	16	20	23	25
4	7	13	18	22	24
3	4	9	15	19	21
2	2	6	11	14	17
1	1	3	5	8	12
	1	2	3	4	5

CONSEQUENCE

Human Safety Review Board

LIKELIHOOD RATING	In-Mission	Flight Recertification	Long Term Health
5 Very High	More likely to happen than not during the mission or probability (P) >10%	Very likely to happen. Controls are insufficient or P> 10%	Likelihood is very high OR >10% excess risk
4 High	Likelihood is high during the mission or 1%<P≤10%	Likely to happen. Controls have significant limitations or uncertainties or 1%<P≤ 10%	Likelihood is high OR 6-10% excess risk
3 Moderate	May happen during the mission or 0.1%<P≤1%	Not likely to happen. Controls exist with some limitations or uncertainties or 0.1%<P≤1%	Likelihood is moderate OR 3-6% excess risk
2 Low	Unlikely to happen during the mission or .01%<P≤0.1%	Not expected to happen. Controls have minor limitations or uncertainties or 0.01%<P≤0.1%	Likelihood is low OR 1-6% excess risk
1 Very Low	Nearly certain to not occur in-mission or P≤0.01%	Extremely remote possibility that it will happen. Strong controls in place or P≤0.01%	Likelihood is very low OR < 1% excess risk

L x C Matrix

LIKELIHOOD \ CONSEQUENCE	1	2	3	4	5
5	5	10	16	20	23	25
4	4	7	13	18	22	24
3	3	4	9	15	19	21
2	2	2	6	11	14	17
1	1	1	3	5	8	12

Time frame
Expected Need for Mitigation

Near	0 < 2 Years
Mid	2-7 Years
Far	> 7 Years

*Consequence Over Likelihood**

Risk Score Card values are constant across all risks and prioritize consequence over likelihood.

CONSEQUENCES		1	2	3	4	5
IN MISSION	Crew Health Impact OR Mission Objectives Impact	Temporary discomfort / Insignificant impact to crew performance and operations – no additional resources required	Minor injury/illness that can be dealt with by crew without ground support, minor crew discomfort / Minor impact to crew performance and operations – requires additional resources (time, consumables)	Significant injury/illness or incapacitation that requires diagnosis and/or treatment support from ground, may affect personal safety / Significant reduction in crew performance, threatens loss of a mission objective	Critical injury/illness of one crew member requiring extended medical intervention and support, may result in temporary disability / Severe reduction of crew performance that results in loss of multiple mission objectives	Death or permanently disabling injury/illness affecting one or more crewmember (LOCL/LOC) / Loss of mission due to crew performance reductions or loss of crew
FLIGHT RECERT	Crew Flight Recertification Status	Immediate flight recertification status	Flight recertification status within 3 months with limited intervention	Flight recertification status within 1 year with nominal intervention or restricted flight status	Flight recertification status requires extended medical intervention and takes > 1 year	Unable to be Recertified for Flight Status, premature career end
LONG TERM HEALTH	Health Outcomes OR Quality of Life	Career related short term self-resolving medical conditions / No impact on quality of life OR independence in activities of daily living	Career related medical conditions manageable with outpatient medical treatments / Minor, short-term impact on quality of life OR rare support required for activities of daily living	Treatable career related medical condition that requires hospitalization for management / Moderate long-term impact on quality of life OR may require some time-limited support for activities of daily living	Chronic career related medical condition requiring intermittent hospitalization or nursing care / Major long-term impact on quality of life OR requires intermittent support for activities of daily living	Career related premature death or permanent disability requiring institutionalization / Chronic debilitating impact on quality of life OR requires continuous support for activities of daily living

Assumptions for Long Term Health Risk Matrix:
- *Long Term Health extends from the end of the post mission time period and covers an astronaut's lifetime.*
- *Conditions considered within the LTH Risk Matrix are those that 1) are related to the astronaut career, 2) are beyond those expected as part of natural aging, and 3) include acute, chronic and latent conditions.*
- *Quality of Life is defined as impact on day-to-day physical and mental functional capability and/or lifetime loss of years*

*not fully consistent with CCP ordering

But ALL the matrices imply that at a sufficiently low Likelihood, one can worry less… **even for catastrophic consequences**.

So… How Good is NASA at Judging What Goes in That Lower, Right-Hand Cell*…and How Comfortable are We Coding It Yellow?

How to make yourself miserable thinking about this:

- Worry that we don't have good data (curse of small N)
- Worry that we fall prey to reasoning fallacies:
  1. "It hasn't happened so far…"
  2. "It happened, but it was due to such weird circumstances that it won't happen again…"
  3. Our analyses/models give a *p* of 10 to the -6th
  4. "It's so incredibly costly to prevent, we just have to accept the risk…"
  5. "If it happens, it happens…"
- Worry that we're not very good at learning from past events

**or equivalent*

Three Risk Examples to Worry About

NASA: In-Space Fires (Issue for Gateway Systems Design)

- Fallacy #2 leads to lack of redundant systems, sufficient training
- Everyone please keep an eye on this (so that I can worry less)

NASA: Space Debris (NORAD Tracks >26,000 Objects* >10 cm)

- Interesting article ("The Trash Nebula") in The New Yorker (9/28/20)
- Describes ISS's near-miss with Object #36912 on 7/16/15, S. Kelly's logs
- Fallacy #1 leads to our inconsistent efforts (or even acknowledging the issue)
- Fallacy #3 leads to insufficient resources being allocated
- Fallacy #4 leads Russians to ignore closing hatches in favor of eating a good lunch before sheltering in the Soyuz (which holds a 3-day food supply)

Pacific NW: Earthquakes (Cascadia Subduction Zone)

- Interesting article (The Really Big One") in The New Yorker (7/13/15)
- Many people resorted to Fallacy #1 (even though it *has* happened before)
- Some retrofitting underway, but many local governments are resorting to Fallacy #3
- Confronted with a possible 9+ quake, Fallacy #4 leads some people to choose wine, craft beer, and cannabis for their emergency supplies

**estimated 100M > 1 mm*

Conclusions (Such as They Are)

Every Great Enterprise Needs People who Worry

- It's fine… Most of us worriers are miserable anyway
- Need to exploit worries to develop mitigations, contingencies, fail-safes, redundancies, and other ass-saving designs and procedures

Don't Be Seduced by Pretty Matrices

- Question cell assignments
- Question cell colorings
- Question resource allocations

Point Out Bad Human Tendencies

- Illuminate fallacies in reasoning
- Illuminate diffusion of responsibility
- Illuminate failures to learn

  Rogers Report (Challenger) ----*(new cover)*----→ CAIB Report (Columbia)

Thank You for Your Attention (and Your Worries)!!