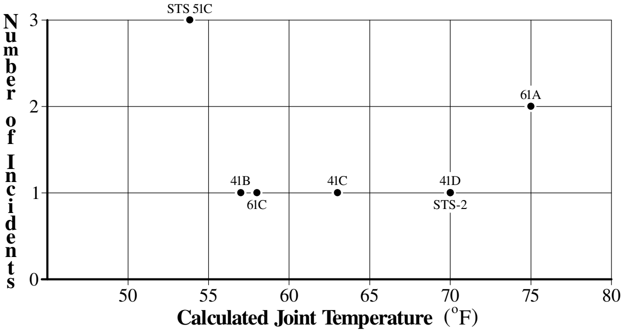
The excerpt EM8913 below is reprinted from the *Journal of the American Statistical Association* **84**(#408), pages 945-957, December, 1989 [DC Library call number: PER QA276.A599x]; the introduction of the article, by Siddartha R. Dalal, Edward B. Fowlkes and Bruce Hoadley and entitled *Risk Analysis of the Space Shuttle: Pre-*Challenger *Prediction of Failure*, is the basis of the information below. It is of interest as an illustration of the use of scatter diagrams in the Analysis stage of the FDEAC cycle and of the possible consequence of assessing a trend from only *part* of a set of bivariate data. [Author Bruce Hoadley is interviewed in Program 16 of *Against All Odds: Inside Statistics* in the segment on the *Challenger* disaster.]

EM8913: On the night of January 27, 1986, the night before the space shuttle *Challenger* accident, there was a three-hour teleconference among people at Morton Thiokol (manufacturer of the solid rocket motor), Marshall Space Flight Center [NASA (National Aeronautics and Space Administration) center for motor design control], and Kennedy Space Center. The discussion focused on the forecast of a 31°F temperature for launch time the next morning, and the effect of low temperature on O-ring performance. A data set, Figure 1a below at the left, played an important role in the discussion. Each plotted point represents a shuttle flight that experienced thermal distress in the field-joint O-rings; the x axis shows the joint temperature at launch and the y axis shows the number of O-rings that experienced some thermal distress. The O-rings seal the field joints of the solid rocket motors, which boost the shuttle into orbit. Based on the U-shaped configuration of points (identified by the flight number), it was concluded that there was no evidence from the historical data about a temperature effect.

Figure 1a. Frequency of O-Ring Distress vs. Temperature



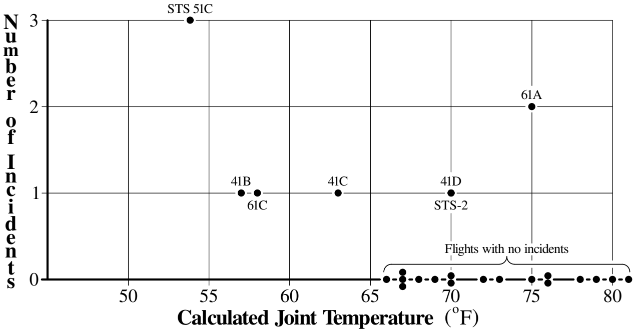
Nevertheless, there was a debate on this issue, and some participants recommended that the launch be postponed until the temperature rose above 53°F – the lowest temperature experienced in previous launches – because the corresponding flight had the highest number of distressed O-rings. Some participants believed, based on the physical evidence, that there *was* a temperature effect on O-ring performance; for example, one of the participants, Roger Boisjoly (see Statistical Highlight #1201), stated: *temperature was indeed a discriminator.* In spite of this, the final recommendation of Morton Thiokol was to launch the *Challenger* on schedule. The recommendation transmitted to NASA stated that *Temperature data [are] not conclusive on predicting primary O-ring blowby.* The same telefax stated that *Colder O-rings will have an increased effective durometer ('harder'), and 'Harder' O-rings will take longer to 'seat'* [Presidential Commission Report, Vol. 1 (PC1), p. 97 (Presidential Commission on the Space Shuttle *Challenger* Accident 1986)].

NOTE: It is interesting to speculate, if (hypothetically) the right-most point in Figure 1a above had involved *one* (instead of two) distressed O-rings, whether the modified Figure (shown at the right) would have been interpreted to yield the *correct* Answer (as in Figure 1b at the right above) about the temperature-O-ring distress relationship.

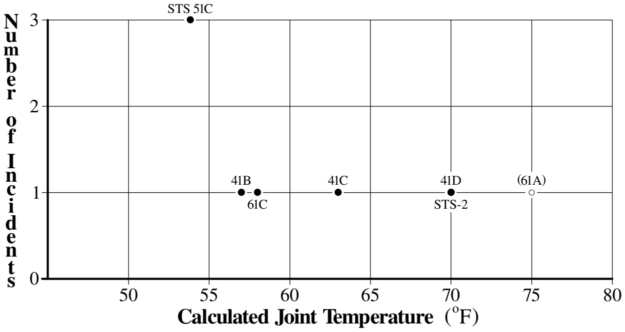
After the accident, a commission was appointed by President R. Reagan to find the cause. The commission was headed by former Secretary of State William Rogers and included some of the most respected names in the scientific and space communities. The commission determined the cause of the accident to be the following: *A combustion gas leak through the right Solid Rocket Motor aft field joint initiated at or shortly after ignition eventually weakened and/or penetrated the External Tank initiating vehicle structural breakup and loss of the Space Shuttle* Challenger *during mission 51-L* (PC1, p. 70). This is the type of failure that was debated the night before the *Challenger* accident.

The Rogers Commission (PC1, p. 145) noted that a mistake in the analysis of the thermal distress data – Figure 1a at the left – was that flights with zero incidents were left off the plot because it was felt that these flights did not contribute any information about the temperature effect (see Figure 1b below). The Rogers Commission concluded that *A careful analysis of the flight history of O-ring performance would have revealed the correlation of O-ring damage in low temperature* (PC1, p. 148).

Figure 1b. Frequency of O-Ring Distress vs. Temperature



This article aims to give more substance to this quote and show how statistical science could have provided valuable input to the launch decision process. Clearly, the key question was: *What would have constituted proof that it was unsafe to launch?* Since our model of the phenomeon is stochastic, our answer is necessarily probabilistic. As in the teleconference, a good start would have been an examination of the thermal distress data – Figure 1b – for the presence of a temperature effect. Nevertheless, the most important question was: *What is the probability of catastrophic field-joint failure if we launch tomorrow morning at 31°F?* Both these issues are addressed in the article.



The article EM8913 reprinted above is used in Figure 3.10b of the STAT 220 Course Materials, in Figure 4.4 of the STAT 231 Course Materials and in Statistical Highlight #31.