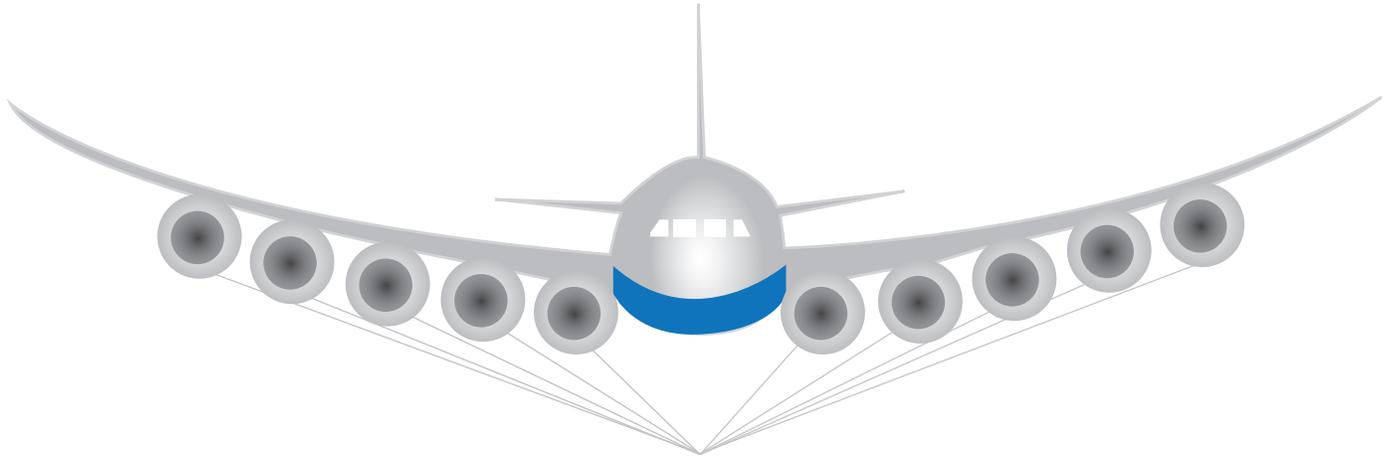


RELIABILITY AND REDUNDANCY



REDUNDANCY = IMPROVED SYSTEM RELIABILITY

Reliable is a great sounding word to describe a product or system. Just what designers and users want to hear. For some, reliability is more than marketing jargon — as in the Department of Defense, Nuclear Regulatory Commission, NASA, aviation, off shore platforms, along with many others. Even though much of this information and material has been around for decades it has yet to reach the HVAC industry.

MIL-STD 721C, “Definitions of terms for Reliability and Maintainability”. A standard just on definitions that is more than 30 years old.

RELIABILITY: 1) The duration or probability of failure-free performance under stated conditions. 2) The probability that an item can perform its intended function for a specified interval under stated conditions. For non-redundant items this is the equivalent to definition 1). For redundant items, this is the definition of mission reliability.

MISSION RELIABILITY: The ability of an item to perform its required function for the duration of the specified mission profile.

With any mission there are consequences of failure — loss of life, major expense to moderate inconvenience.

Reliability is a **PROBABILITY**. In some cases 88% reliability could be “fine” ... do something 100 times and plan/budget/expect 12 failures. Reliability decreases with time and/or the likelihood of failure increases with time.

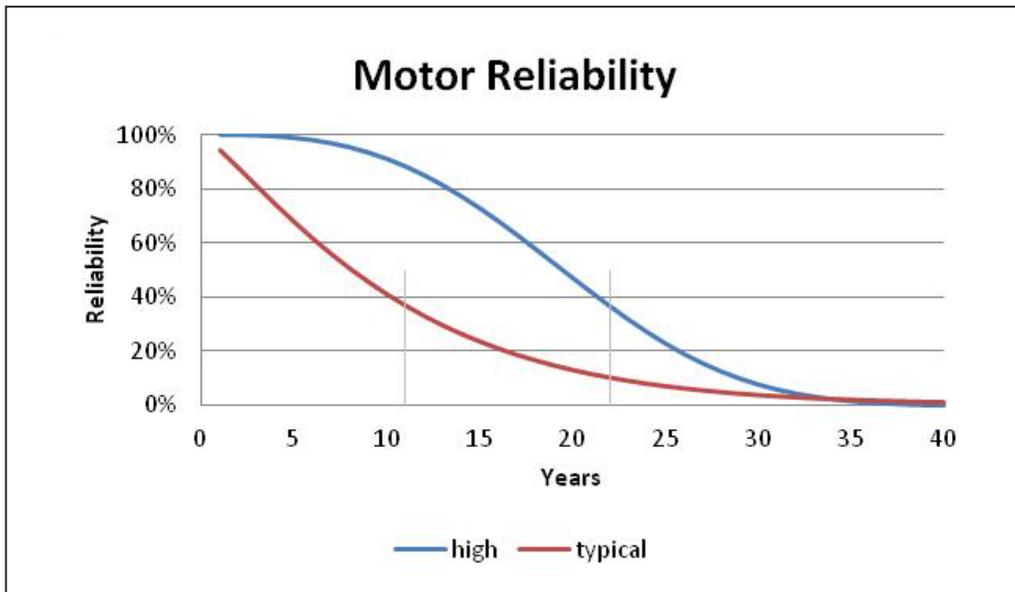
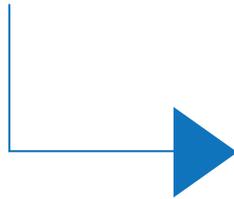
Probability involves a distribution and a failure rate (average life). Normal, exponential, lognormal and Weibull are examples of common distributions. Failure rate may come from testing, surveys, historical records, etc.. Many references acknowledge Weibull as the preferred distribution. Weibull distribution enables the failure rate to be adjusted to failure records (high or low infant mortality, end of life wear out, etc).

In the case of a direct drive fan, the induction motor is the most likely point of failure. What is the average life of an integral horsepower induction motor? Simple question — no simple answer. “Average motor life is somewhere between a few days and a few decades” — an accurate answer but not very useful.



MOTOR LIFE is: 1) proprietary with sensitive implications to a manufacturer 2) following the warranty period there is a disconnect between the manufacturer and the user, 3) what is a failure? new bearings and/or windings are repair or failure? The motor industry and their trade associations are not the best resource. There are DOD references: Handbook of Reliability Prediction Procedures for Mechanical Equipment (NAVSEA) Chapter 14 – lists the base life of a polyphase AC motor at 100,000 hours. Many references are made to a 1980 Department of Energy report (DOE/CS -014) – for 7.5hp thru 50hp motors average life is 20.6 years. “Documented Savings No 20–Induced Draft Fans”, Baldor*Reliance, average life for a cooling tower motor is 15 years. Barringer & Associates, (www.barringer1.com), a reliability consultant, offers an extensive amount of information. *AC motors are listed with a “typical” life of 100,000 hours, and a “high” range of life at 200,000 hours.*

For a motor in an air handling unit the environment is conditioned and filtered, the load is variable torque, there is no coupling or belts and there is a VFD.



This is a graphical presentation of the material presented by Barringer and Associates. “High” life (μ) is 200,000 hours [Weibull shape parameter (β) is 3]. “Typical” life, $\mu = 100,000$ and $\beta = 1.2$. In terms of background information: $\beta < 1$ decreasing failure rate (high infant mortality), $\beta = 1$ constant failure rate, $\beta > 1$ increasing failure rate (high reliability early, wear out later in the life cycle). *In any and all cases, reliability at average life is 37%. At average life, 63% of the population is expected/predicted to have failed.* A fraction of the population will remain in operation well beyond “average” life.

PROBABILITY DOES identify when a specific component will fail. Any given component could fail on day one or operate well beyond average life. Reliability applies to a population — quantity one or quantity 100 does not change the reliability of the population. As quantity increases there are more opportunities for failure. A 12% likelihood of failure in group of 1 (mental math $12\% \times 1 = 0.12$ failed) is different than in a group of 10 ($12\% \times 10 = 1.2$ failed).

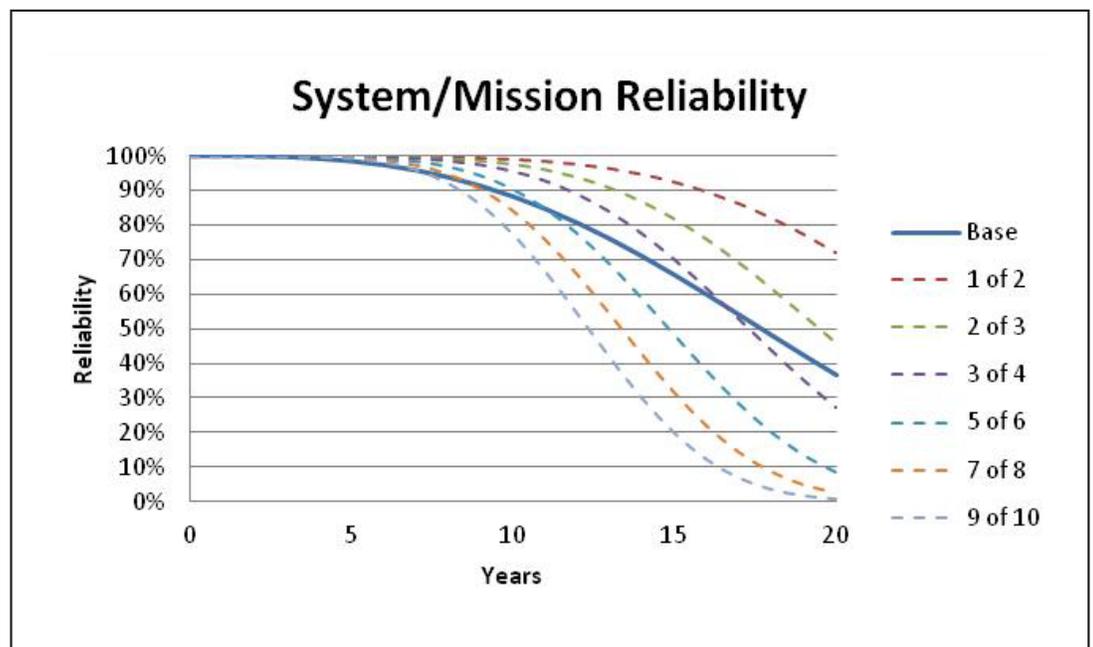
PROBABILITY IS NOT a guarantee. 99.99999% reliability is warranted on a high risk/cost endeavor but uncertainty still exists (risk). An example of reliability centered maintenance is the initiation of a pre-mediated repair when the cost/risk of an unplanned shutdown exceeds the cost of a planned repair. Redundancy is another example where higher system reliability is required/desired.

REDUNDANCY: "The existence of more than one means for accomplishing a given function. Each means of accomplishing the function need not necessarily be identical." (MIL-STD 721C)



"n-1" is a trendy topic in HVAC (chillers, boilers, compressors, fans). This is not some new approach in the reliability world.

Here is system reliability with **n-1 redundancy**. Each individual component has "base" reliability ($\mu=200,000$ hours, $\beta=3$). Through the first five years quantity/redundancy does little for system reliability. Through the first ten years, quantity 8 and quantity 1 provide essentially the same reliability. At 10 years base reliability is 88%, with 78% for 9 of 10 and 99% for 1 of 2. This should follow intuition, the chance of having 1 of 2 is higher than 1 of 1 while the chance of having 9 of 10 is not as high.



With a 100% at “n-1” design, quantity can impact the size (hp) of the individual component. At quantity two, each component must be sized to match the total load. At quantity 10, each component must meet 1/9 of the load. *An important question ... is 100% at n-1 actually a requirement or simply a convenience?* 70% redundant capacity will address many critical applications, especially on a short term basis. Redundant capacity and system reliability tend to create something of a conflict — a higher probability of maybe less redundant capacity versus a lower probability of higher redundant capacity. The fan system is only one element within the AHU – VFD, circuit breaker, coil, temperature control valve, circulating pump — “each means of accomplishing the function need not necessarily be identical.”

While some HVAC requirements are extremely critical, few mimic a mission to Mars. A major difference — repairs are possible; the system/mission reliability graph does not consider repairs. By definition infinite repairs offer a very high probability of success. With time the population becomes a blend of “old” and “new”. The old population tracks the original reliability and each repair represents a new population. The relationship between probability and quantity does not change, 63% of the population fails by average life. At quantity one, 50% reliability represents 50/50 odds. The odds of failing equal the odds of not failing.

Here is one method to compare **BLENDED POPULATIONS**:

qty 1 x 50% failure = 0.5 assume a failure
qty 10 x 5% failure = 0.5 assume a failure (1st in original population and 1 new life)
qty 9 x 17% failure = 1.5 assume a failure (2nd in original population and 2nd new life)

*each replacement operates as a quantity 1 sample and fails at 50% base reliability
*assume all quantities (sizes) have the same reliability

FOR QUESTIONS OR ADDITIONAL INFORMATION,
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