

TC Design Methods for Reliable Lead-free Products

World Class Reliability MOEST: Multi Environment Over Stress Testing

TNO | Kennis voor zaken

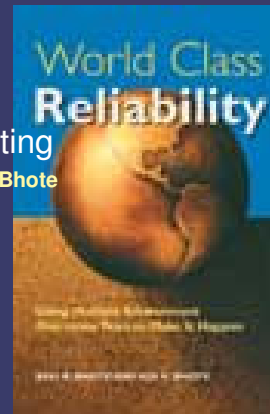


Climbing the Mount Everest of Stress Testing

Source: World Class Reliability, ISBN 0-8144-0792-7 Keki R. Bhole

Session 3 MOEST

Jan Eite Bullema
Technology Manager Micro Technology



Reliability Approach

- 1 Identify product functions
- 2 Identify mission profile / normal usage conditions / Design Tolerances/ Engineering Tolerances / Customer Tolerances
- 3 Estimate potential root causes for failure (FMEA)
- 4 Define appropriate tests / accelerated tests
- 5 Execute tests / accelerated tests / **MOEST**
- 6 Analyze products and failures
- 7 Identify root causes for failures in tests
- 8 Statistical analysis (preferably through Weibull)
- 9 Determine acceleration factors were appropriate
- 10 Predict reliability behavior under normal conditions, identify design flaws
- 11 When necessary iterate from appropriate step
- 12 Reporting

2



Jan Eite Bullema

Biography Keki R. Bhote Author of World Class Reliability

Mr. Keki Bhote was born in Bombay, India in the 2nd quarter of the 20th century, where he received his early education. He received his B. Sc. degree in Telecommunication engineering from the university of Madras, India, and his M.Sc. in Applied Physics and Engineering Sciences from Harvard University. Upon completion of his studies, he joined Motorola as a development engineer, and rose through the ranks to become Group Director of Quality and Assurance for Motorola Automotive and Industrial Electronics Group before promotion to Senior Consultant for the entire corporation world-wide. Since his retirement from Motorola, Keki has been in private practice providing Telecommunication consulting.



3



Jan Eite Bullema

Why MEOST?

Dramatic Reduction in Development Time

Multiple Environment Over Stress Tests (MEOST), first developed at NASA to test the Lunar Module, achieves:

- Reliability levels of 10:1 to 100:1 over traditional field reliability.
- Reductions in design validation time from over 16 weeks to less than 2 days.
- Reductions in design test costs by factors of 5:1.
- Reductions in design sample sizes by factors of 10:1.
- Faster designs to the market, leaving competition in the dust.

MEOST Principles are:

- Testing to failure is more important than success testing.
- Environments/stresses must be combined to produce interaction failures.
- Stress levels must go well above design stress – almost to total destruct levels to reduce the time to failure.
- The rate of stress level increases must be very rapid to reduce time to failure by one or two orders of magnitude.

4



Jan Eite Bullema

Why MEOST?

Large Variances in Failure Estimates

National Handbook	FITs	% per year
MIL Handbook 217 (US)	4240460	317.3
BT (Brittain)	700	11,6
CNET (France)	37870	33.0
NTT (Japan)	37940	33.1

Prediction for the same large memory board, the difference is over 600 : 1.
So much for cookbook accuracy! [Kam L. Wong, 'The bathtub curve does not hold water anymore', Quality and Reliability Engineering Symposium 1988]

The handbooks consider part complexity, part technology, package technology, part application, electrical stress, temperature and manufacturing quality control level for their failure rate projections. They do this with exponential extrapolations and multipliers.

5



Jan Eite Bullema

1. Why do the Handbooks Fail?

The handbooks consider part complexity, part technology, package technology, part application, electrical stress, temperature and manufacturing quality control level for their failure rate projections. They do this with exponential extrapolations and multipliers. What is not considered (or limited) are the following factors:

1. Temperature cycling.
2. Failure rate changes with material.
3. Vibration
4. Nonoperating failure rates.
5. Combined Environments.
6. Supplier Variations Affecting reliability.

6



Jan Eite Bullema

2. Why do the Handbooks Fail?

1. Temperature cycling. Failures accelerate with 1) the number of thermal cycles and 2) the wider range from cold to hot. Failures can increase sevenfold with these two factors alone. In addition, the rate of temperature change - from example 1 - 2 degrees per minute to 25 to 40 degrees per minute generates far more rapid failures.

These are very important in MOEST tests.

2. Failure rate changes with material. For brittle materials, a higher rate of temperature change accelerates failures whereas ductile material such as aluminium and solder, a lower rate of temperature change accelerates failure.

3. Vibration: sensitivity to exact installation and mounting structure. The amplitude of vibration can vary with a product, depending on the exact installation and the mounting structure. Each unit would have its own response spectrum and, hence, its known failure rate when subjected to the same vibration input

7



Jan Eite Bullema

3. Why do the Handbooks Fail?

4. Nonoperating failure rates. It may come as a surprise that non-operating products systems are still subject to environmental stresses. These non-operating or zero stress- failure rates vary under different storage or shipping conditions. Many missile storage studies have found that failure appear to be independent of the length of storage. This strongly suggest that turn-on was the culprit in most of these failures.

5. Combined Environments. While temperature cycling and vibration are the two most important stress/environments causing failures, the handbook do not take into account other stresses, such as humidity, dust, altitude, power cycling, transients or radiation. Yet their effect in simultaneous combination can not be ignored.

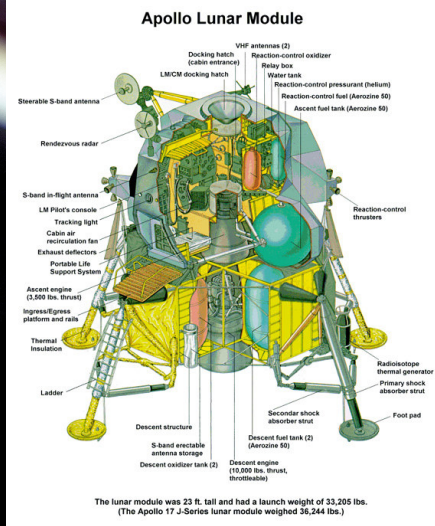
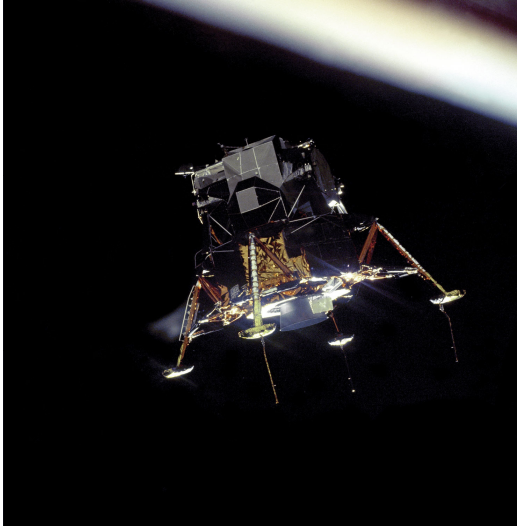
6. Supplier Variations Affecting reliability. Handbooks do take into account reliability specifications imposed on suppliers, such as verification of parts mechanical integrity, long term measurement failure rates, minimum life expectancy, extend of parametric measurements, and the amount of environmental screening . But not all reliability requirements can be specified; if they were, the costs would be prohibitive.

8



Jan Eite Bullema

First Application of MEOST in the Apollo Lunar Module



9



Jan Eite Bullema

MEOST = Multiple Environment Over Stress Testing

Bhote: 'Climbing the Mount Everest of Reliability Testing'

From base camp to the summit

- Life Testing
- Burn-In Testing
- Cycling Testing
- Single Environment Testing
- Accelerated Testing
- Multi Environment Testing



Source: World Class Reliability, ISBN 0-8144-0792-7 Keki R. Bhote

10



Jan Eite Bullema

Life Testing

Bhote: 'Reliability Demonstrating: Throwing Money at the Problem'

In the early life testing of the 1960s, a sample of product was simply allowed to 'cook' for 1000 to 3000 hours to detect failures. As expected a few failures were uncovered.

11



Jan Eite Bullema

Burn-In

Bhote: 'If you don't know what else to do'

To subject units (especially electronic products) to a high temperature soak for twenty-four to ninety-six hours, on a 100 % basis.

Minor tinkering around the edges added electrical power to the units subjected to burn-in, along with the cycling of power 'on' and 'off'

Strangely this is still the preferred method of demonstrating reliability. Even more incredibly, many customer insists on burnin as proof of reliability.

12



Jan Eite Bullema

Thermal Cycling Testing

Bhote: 'The Dawn of True Reliability Progress'

In the mid-1960s the principle of exercising stress on parts and products through temperature cycling was introduced. Within a decade thermal cycling advanced in seven stages.

Stage 1:	Thermal Cycling, no electrical power
Stage 2a:	Thermal Cycling, continuous power
Stage 2b:	Thermal Cycling, interrupted power
Stage 3:	From 0 °C to 50 °C , 1 cycle
Stage 4:	5 Cycles with Measurements at Temperature Extremes
Stage 5:	Extension from – 30 °C to 85 °C, 25 Cycles
Stage 6	Extension to > 100 Cycles

13



Jan Eite Bullema

Vibration Cycling Testing

A companion development

Parallel to thermal cycling, advances were also made in vibration to simulate product failures

Stage	Specific Technique
1	Sinusoidal
2	Single Axis, Single Frequency
3	Sine Sweep
4	Random
5	Random with 6 degrees of freedom (in 3 distinct axes and 3 rotational axes simultaneously)

Other Stresses/Environments

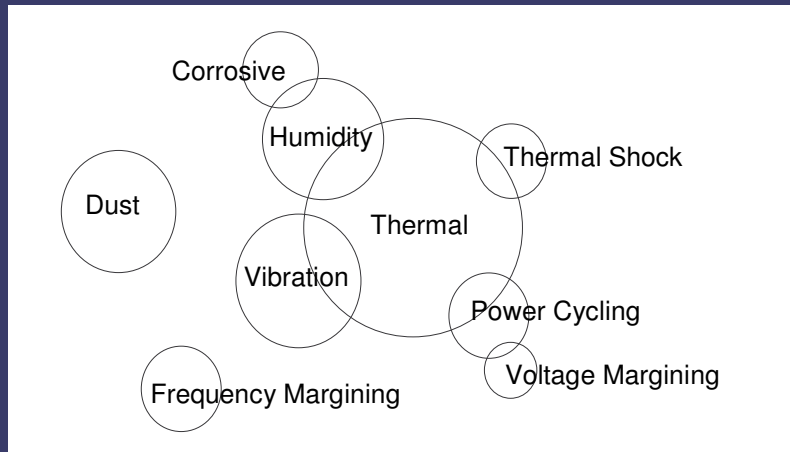
Thermal Shock, Humidity. Power Cycling, Voltage Margining,

14



Jan Eite Bullema

Crude Approximation of the Relative Influences of Various Stresses and their Actions



Single Environment Testing

Bhote: 'Another False Start'

In an attempt to achieve a better reliability, some automotive and electronic companies initiated a long and tortured test regimen, wherein a product would be subjected to a series of separate, single environment stresses, but in sequence.

A typical sequence would be: test, thermal cycling; retest; vibration retest, humidity, retest, etc.

(Highly) Accelerated Testing

Methodology

Performed at the prototype stage of design, HALT stresses a product well beyond design specifications right up to destruct levels, or a fundamental level of technology.

One interpretation of a destruct level is that it's a level stress at that level where a small (further) level of stress causes a large increase in the number of failures.

A third interpretation is the fundamental limit of technology (FLT), which is defined as that level of stress where the product disintegrates.

HALT generates multiple failures, a few in the lower stress levels and a large number of rapid failures as the stress approaches destruct levels.

Accelerated Testing

An Overview

HALT:

HASS: Highly Accelerated Stress Screening. Is a 100% test screen with stresses higher than field stress. High enough to catch potential field defects, but leave the rest of the product with > 80% of its useful life

HASA: HASA starts with 100 % sampling, but allows for lower sample sizes if the number of failures drops below a specified level

ESS: Environmental Stress Screening came into vogue twenty-five years ago as an alternative to burn-in and mil spec series. HALT and HASS were the off spring of ESS

Preparation for MEOST

1. Choosing Appropriate Product Levels
2. Prioritize current Field Failures
3. Ruggedizing a Product for MEOST
4. Setting appropriate stresses in combination
5. Determine Limits (Design, Operational, MPOSL and Destruct)
6. Determine the number of stress levels
7. Allowing enough Dwell time at each stress level
8. Establish a Combined Stress Scale
9. Prepare the Stress Sequencing Roadmap
10. Determine Outputs (green Ys)
11. Setting up adequate support Equipment
12. Choosing Sample Size for MEOST

19



Jan Eite Bullema

Typical Stress Levels for MEOST

- 200 % **Destruct Stress**
Either continuity of failure (HALT) or fundamental level of technology)
- 170 % **Maximum Practical Over Stress (MPOSL)**
MPOSL is midway between operational and destruct level
- 130 % **Operational Stress**
Operational stress is that stress that which, when reduced, causes the failure to be reduced (HASS level)
- 100 % **Design Stress**
Highest of: (1) Engineering Specifications, (2) Customer requirements, (3) Maximum Field Environment.
- 0 % **Room Ambient**

20



Jan Eite Bullema

Choosing Sample Size for MEOST

Recommended Guidelines are as follows

MEOST Stage	Sample Sizes
Prototype (stage 3)	3 for repairable 5 to 10 for non-repairable units
Pilot run (stage 4)	5 to 10 for repairable units 15 to 25 for non-repairable units
Subsequent stages	5 to 10 for repairable units 15 to 25 for non-repairable units

21



Jan Eite Bullema

Sample Size for MEOST (1)

One of the most frequent doubts expressed by managers and engineers exposed to MEOST for the first time is: How can the small, no tiny sample size of 3 to 10 units in MEOST testing adequately represent the total population of the product? After all, statistics tell us that sample sizes of 30 to 50 to 100 units are minimum required.

The answer is that in MEOST, we are not concerned with failures as a percentage of the total number of units tested. We want to probe the weakest components that, by the laws of physics, have stresses two or three times higher than the strongest components and therefore are likely to fail the quickest.

22



Jan Eite Bullema

Sample Size for MEOST (2)

Under normal field conditions it would take a long time for even these weak components to fail. However, Miners equation indicates that for even doubling the stress, the failure rate can jump $2^{10} = 1024$ times. As a result the distribution of failures for several components, which may be bunched up under benign field conditions, are going to spread out under accelerated stress. And there will be a wide separation between the early failures of the weak components and the late failures (Or no failures) of the more robust components.

In MEOST stages 3 to 8 one failure per failure mode is allowed in overstress regions. The reason is that a single, lone failure may represent an anomaly. As a change occurrence, it represents an extreme low end of the failure distribution of that component and can be ignored.

Two failures of the same failure mode is the start of a trend and should be analyzed and checked.

23



Jan Eite Bullema

Preparation for MEOST

1. Choosing Appropriate Product Levels
2. Prioritize current Field Failures
3. Ruggedizing a Product for MEOST
4. Setting appropriate stresses in combination
5. Determine Limits (Design, Operational, MPOSL and Destruct)
6. Determine the number of stress levels
7. Allowing enough Dwell time at each stress level
8. Establish a Combined Stress Scale
9. Prepare the Stress Sequencing Roadmap
10. Determine Outputs (green Ys)
11. Setting up adequate support Equipment
12. Choosing Sample Size for MEOST

24



Jan Eite Bullema

The Eight Stages of MEOST

1. Single Stress Up to the Design Limit
2. Single Stress Up to the Maximum Practical Over Stress Limit
3. Prototype – Full MEOST to Maximum Practical Over Stress Limit
4. Pilot Run
5. Mini-MEOST in Outgoing Production
6. First Round of MEOST on Field Returns
7. Second Round of MEOST on Field Returns
8. Cost Reduction

25



Jan Eite Bullema

Stage 1 of MEOST:

Single Stress Up to the Design Limit

This is a preliminary stage to determine the failure contribution, if any, of each single stress selected in the four or five stresses that will eventually be used in combination.

- Step-stress in three or four stress levels, from room-ambient benign stress up to the design limit for that stress
- Start with thermal cycling -20 to 80 in 40 C per minute, applying a dwell time of 10 minutes, start cold then hot
- For vibration , start with zero and go up to design stress
- Repeat with other single stresses , such as humidity, voltage, transients, and shock
- If there is even a single failure, correct it and validate the effectiveness of the correction using a B vs. C test

26



Jan Eite Bullema

Stage 2 of MEOST

Single Stress Up to the MPOSL

Stage 2 is also a preliminary stage to determine the effect of overstress of each single stress used in Stage 1.

- Continue stage 1 beyond the design limits for each stress on the same unit (if repairable to MPOSL)
- If there are no failures in the overstress region continue testing a few cycles for a few hours
- If there are still no failures we can conclude:
 - The stress type is inadequate
 - The rate of stress is too slow
 - The test has not been executed properly

27



Jan Eite Bullema

Stage 3 of MEOST (1):

Prototype-Full MEOST To MPOSL

This is the most important MEOST stage. When completed it assures the designer to the best advance possible in reliability by forcing the weak links in design to be smoked out.

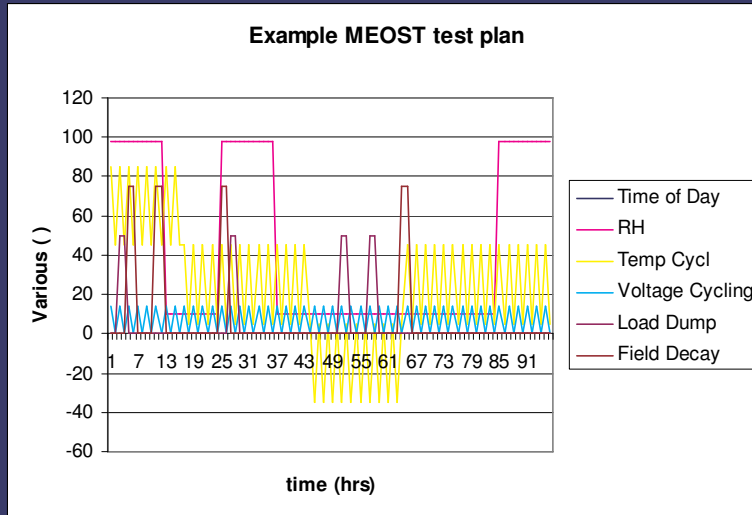
- Select the four/five stresses that are likely to impinge simultaneously on the product in the field
- Prepare a combined stress sequencing roadmap
- Use the same units that have survived stage 1 and 2, if possible and subject them to combined stresses
- Start at design stress and then step stress intervals to MPOSL
- Procedure similar to stage 2, but with multiple stresses
- If there are no failures continue the cycles for 24 hours

28



Jan Eite Bullema

Example MEOST Test Plan

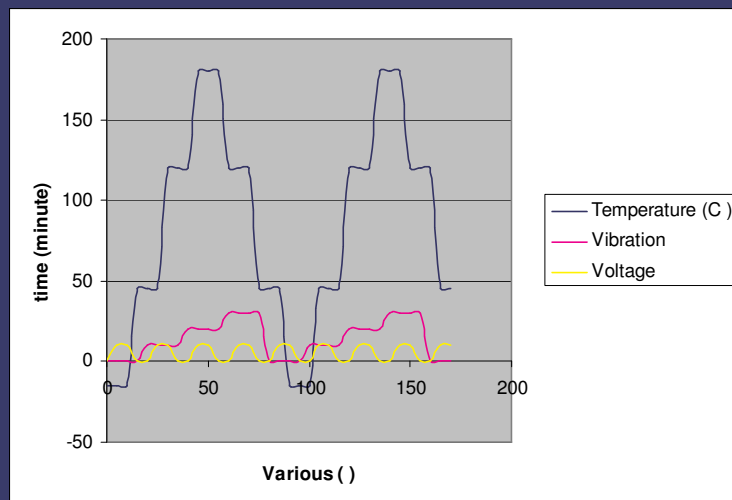


29



Jan Eite Bullema

Typical MEOST Test Profile



30



Jan Eite Bullema

Stage 3 of MEOST (2): *Prototype-Full MEOST To MPOSL*

- If there are two or more failures per failure mode, that are different from the predominant failure in the field, then there are several possible reasons: (1) field data not OK , (2) stresses have to be added, (3) stress levels or rate has to be increased
- Perform another round of stage 3 with deliberate 'seeded defects' to confirm MEOST effectiveness
- Design improvements to correct the above failure mode(s) and validate the effectiveness of the improvement with B vs C tests

Because there are only a few prototype samples that can be spared for any kind of testing, the sampling is 3 to 5 units

31



Jan Eite Bullema

Stage 4 of MEOST: *Pilot Run*

This stage of MEOST ensures that design improvements/changes, tooling, suppliers, processes, and fixtures have not adversely affected design reliability

These steps are as follows:

- Run a stage 4 MEOST, using the same guidelines as stage 3, with new units from an engineering or production pilot run.
- A successful outcome means that the design is now ready for full production.

32



Jan Eite Bullema

Stage 5 of MEOST:

Mini-MEOST in Outgoing Production

Stage 5 ensures that reliability integrity of the design is not Degraded by manufacturing processes, workmanship, and supplier materials. The steps are as follows:

Repeat Stage 3, with two major exceptions

- Reduce one or more of the four or five stresses used in stage 3 and 4
- Reduce the overstress from the Maximum Practical Overstress Level to the operational level (approximately one-third above the design stress)

Sample size 3 to 5 units for production runs of 100 to 1000 units per day. Never use 100 % sampling. 1 to 3 units for production runs of less than 100

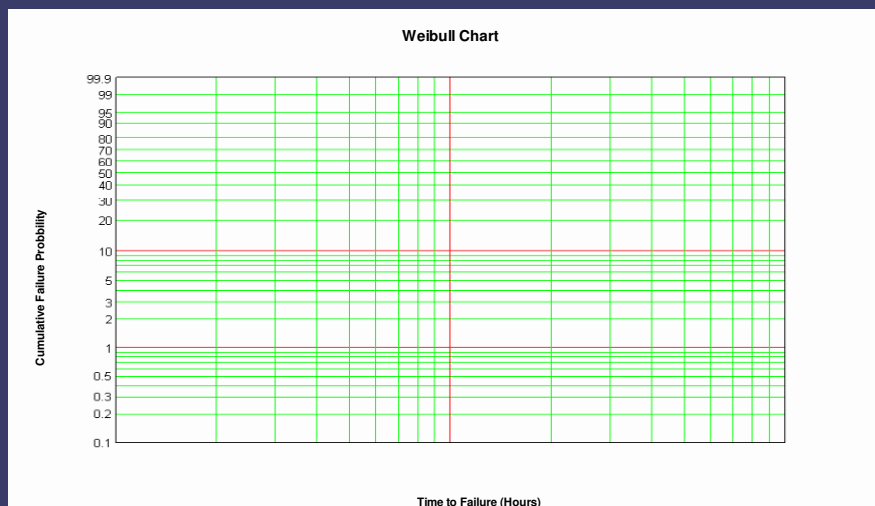
33



Jan Eite Bullema

Weibull Chart

$$f(t) = \frac{\beta}{\eta} \left(\frac{t - \gamma}{\eta} \right)^{\beta-1} e^{-\left(\frac{t - \gamma}{\eta} \right)^\beta}$$



34



Jan Eite Bullema

Stage 6 of MEOST:

First Round of MEOST on Field Returns

Stages 1 to 5 are all performed virtually at time zero in their product life. Hence plotting the failures or stresses on a Weibull plot will yield only one point in the graph. Stage 6 purpose is to secure a second point on a Weibull plot after a period of exposure in the field – typically six months in service

- Make arrangements with a trusted, competent customer
- Request 5 – 10 good units to be returned in exchange for new units
- Subject these to a stage 3 MEOST starting with Design to MPOSL
- Record the percentage of overstress when there are 2 or more failures
- On a Weibull plot, record the time to failure for time = 0 (overstress stage3) and t = field exposure (overstress stage 6)

Now we have two point on a Weibull Chart

35



Jan Eite Bullema

Stage 7 of MEOST:

Second Round of MEOST on Field Returns

It takes at least three points on a Weibull plot to draw a best-fit straight line connecting them and extrapolating the straight line.

A new point is generated using the same procedure as Stage 7 with the difference that a longer exposure time in the field is required -typically one year in service.

- Add a point on the Weibull chart depicting one year in service

With three points on the Weibull plot – at time zero, six months and one year. Draw the best fit straight line and extrapolate it until it reaches the design stress horizontal line.

Projected on the x-axis, this intersection records the years to failure and hence depicts reliability of the product.

36



Jan Eite Bullema

Stage 8 of MEOST: *Cost Reduction*

Use a value engineering approach:

1. List all the high cost items in the product and prioritize them in terms of highest costs and importance.
2. For the top three or four of the high priority items, use a value Engineering approach to determine their function
3. Using brainstorming and other related methods, determine what other part will provide the function at least cost,
4. Substitute the value engineered parts for the more expensive original parts and run functional tests
5. Run MEOST studies on both B and C products with three Bs and Cs *in random order.*

37



Jan Eite Bullema

8 Stages of MEOST *Conclusion*

The seven stages of MEOST, along with stage 8 to explore cost reduction potentials of the design, contribute the best, quickest and cheapest and most powerful approaches to reliability enhancement known.

It is also a recipe for getting truly mature product into the marketplace way, way ahead of the competition

38



Jan Eite Bullema

Questions?



Edmund Hillary and Tenzing Norgay about to leave the South Col to establish camp IX below the south summit. May 1953