nature materials Vol. 2 No. 6 June 2003 www.nature.com/naturematerials

It's not rocket science — or is it?

The 1 February 2003 loss of NASA's Columbia space shuttle on its re-entry to the atmosphere was, to all accounts, an accident waiting to happen. There was a variety of different technical and managerial factors that could have led the ageing shuttle to fail. But as the space agency's admirably painstaking investigation into the accident unfolds, two particular technical failures are emerging as key elements in this particular disaster. As it happens, both concern materials used in the Space Shuttle programme.

The accident was instigated, investigators believe, about a minute and a half after the space shuttle's launch on 16 January. As the launch rocket gathered speed, large pieces of orange insulating foam — which is wrapped around the main booster rocket's cryogenic fuel tanks to keep them cool — crumbled off. Video shot at the time clearly shows some of the foam pieces striking the leading blade of the shuttle's left wing, where failure was to occur on re-entry two weeks later.

Dramatic as it might look to lay observers, the crumbling of the foam and its collision with the space craft at impact speeds approaching 800 km per hour was not especially alarming to shuttle engineers, who had observed it many times before. They regarded the foam as insignificant in its impact with the shuttle's robust structure.

That would have been a reasonable judgement, but for two factors that have emerged during the investigation. One concerns the possible condition of the foam itself. The showering of it onto the shuttle during take-off, it turns out, has only been a regular occurrence since 1997, when NASA and one of its contractors decided to abandon their previous use of freon gas to apply the foam, in an attempt to help save the ozone layer. The substitute method of application seems to have left the insulating layer far less resilient than was previously the case.

Examination of another shuttle fuel casing by accident investigators has found dozens of flaws in one small area of foam, including air pockets up to 50 mm in diameter and failed bonding between foam layers. Such faults not only encourage the crumbling, but may also accommodate ice or other solid debris that is far more likely to damage the shuttle than the soft foam itself.

The second factor concerns the likely resilience of the shuttle to this gentle bombardment. The wing edges, which experience the fiercest heat on re-entry to the Earth, are protected by edge panels, separated by T-shaped seals. Each set of components is made of carbon–carbon composites (actually carbon fibre criss-crossed in graphite), selected for their structural resilience at high temperature.

THE NASA INVESTIGATION INTO THE RECENT SHUTTLE ACCIDENT FOCUSSED ON THE ORANGE FOAM THAT ENCASED THE MAIN BOOSTER ROCKET.

CAIB PHOTO BY RICK STILES 2003

Although such composites are the obvious material for this application, at high temperatures their structural properties can deteriorate over time due to oxidation. In some cases, this can lead to heat ingress and additional stress, so the oxidation effectively tunnels through the material, weakening it while the surface remains sound. To monitor such potential damage and to assure the long-term integrity of the composite, non-destructive testing is needed, but this is inherently difficult for composites. Nonetheless, new ways of non-destructive testing using ultrasonic or other means are now being developed. Mick Peterson of the University of Maine, for example, will present an ultrasonic technique for this at the International Conference on Composite Materials at San Diego next month (July).

However NASA administrator Sean O'Keefe has admitted that the agency relied on simple visual inspection of these critical components to assure their condition between each exacting mission. (Samples of the panels and seals were subjected to rigorous destructive testing during manufacture, but that doesn't provide any information about subsequent deterioration during the lifetime of the component).

It isn't reasonable to expect that any single organization — even one of NASA's pedigree — will always keep itself at the cutting edge of every technology it uses. And as the European, Chinese and Japanese space agencies can each testify after recent unmanned launch failures, sending hardware into orbit remains a challenging business.

Nonetheless, the picture emerging from the shuttle investigation is of a US space agency that isn't the NASA of old, which was characterized by exhaustive attention to engineering detail, alongside a keen readiness to innovate. Manned space flight will never be 'safe', but agencies that attempt it must be firmly grounded in each of these traits.