KALPANA : THE POWER OF IMAGINATION

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I stand before you, with mixed feelings. As an aviator, even though one who is now done with aviation, I recognize the momentous occasion that this is: the centennial of powered flight, a celebration of the day a 100 years ago when the Wright flyer took to the air for the first time. Then again, as an Indian and a Space buff, like most everybody on this Planet, I grieve the passing on of Kalpana Chawla and her 6 colleagues who perished when Columbia started disintegrating over Texas on 01 February this year. While on the one hand I am amazed, in technological terms, of the advancement achieved in the field of Aerospace in the hundred years just gone past, as a professional I remain curious and very interested in knowing what exactly went wrong with Columbia; what the contributory factors were and whether there is a message embedded for us, somewhere in the pages of the voluminous investigation report.

I, therefore, intend to share the report with you as part of this, the First Kalpana Chawla Memorial Lecture. During this time, we shall examine the accident from various aspects. I shall attempt to bring out the message that seems to be hidden and that which, I hope, will serve to make not only Indian Space programmes but also our aeronautical programmes, safe and successful. I have borrowed heavily from the Columbia Accident Investigation Board’s report, which was submitted in Sep 2003 to the US Government, some 7 months after the accident. Admiral Harold Gehman Jr headed the Board.

Physics dictates that to reach orbit, without falling back to Earth, we have to exceed about 28500 kmph. If we cannot vary performance, then the only thing left to change is the amount of payload -the rocket designers began with small payloads and worked their way up. Rockets, by their very nature, are complex and unforgiving vehicles. They must be as light as possible, yet retain outstanding performance to get to orbit. Mankind, thankfully, is getting better at building them. In the early days more often than not, the vehicle exploded on or near the launch pad; that seldom happens any longer. It was not that different from early airplanes, which tended to crash about as often as they flew. Aircraft seldom crash these days, but rockets still fail between two-and-five percent of the time. This is true of just about any launch vehicle -Atlas, Delta, Soyuz, Shuttle regardless of which nation builds it or what basic configuration is used; they all fail about the same amount of the time. Building and launching rockets is still a very dangerous business, and will continue to be so for the foreseeable future while we gain experience from it. It is unlikely that launching a space vehicle will ever be as routine an undertaking as, say, commercial air travel - certainly not in the lifetime of anybody in this auditorium. Scientists and engineers are continually working on better ways but, as of now, if we want to go into outer space, we must continue to accept the risks.

With this as a preamble let us begin the journey.

I shall be touching upon Kalpana’s remarkable journey from Karnal to Near Earth Orbit in the Introduction segment of my talk before covering STS -107’s Mission Background. Thereafter, I shall cover the Accident itself, the Analysis Process and the Learning that came out of it, before concluding.

Introduction

This is where I would like to introduce the remarkable Kalpana Chawla.

Education

She graduated from Tagore School, in Karnal in 1976 and then obtained a Bachelor of Science Degree in Aeronautical Engineering from Punjab Engineering College. Left for the US thereafter and got a Master of Science Degree in Aerospace Engineering from University of Texas, in 1984. Later, in 1988, a Doctorate of philosophy in Aerospace Engineering from the University of Colorado.

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NASA Career

In the same year she started work at NASA Ames Research Center in the area of powered-lift computational fluid dynamics. Her research Centered around the simulation of complex air flows encountered around aircraft such as the Harrier in "ground-effect." In 1993 Kalpana joined Overset Methods Inc., Los Altos, California, as Vice President and Research Scientist to form a team with other researchers specializing in simulation of moving multiple body problems. She was responsible for development and implementation of efficient techniques to perform aerodynamic optimization.

Selected for NASA, Kalpana reported to the Johnson Space Center in March 1995 as an astronaut candidate in the 15th Group of Astronauts. After completing a year of training and evaluation, she was assigned as crew representative to work technical issues for the Astronaut Office, EVA/Robotics and Computer Branches. Her assignments included work on development of Robotic Situational Awareness Displays and testing Shuttle Control software in the Shuttle Avionics Integration Laboratory.

In November 1996, Kalpana Chawla was assigned as mission specialist and prime robotic arm operator on STS-87 (November 19 to December 5, 1997). STS-87 was the fourth U.S Microgravity Payload flight and focused on experiments designed to study how the weightless environment of space affects various physical processes, and on observations of the Sun's outer atmospheric layers. After her first flight on STS-87 she was assigned to STS-107, which was a Near Earth Orbit Mission. On this one she worked with experiments on Astroculture, Advanced Protein Crystal Facility, Mechanics of Granular Materials and the Zeolite Crystal Growth Furnace.

Aviation Experience

Apart from all this and her love for hiking, back packing and reading, she found time for Aviation.

She held a Certificated Flight Instructor's license with airplane and glider ratings, Commercial Pilot's licenses for single- and multi-engine land and seaplanes, and Gliders, and an instrument rating for airplanes. She enjoyed flying aerobatics and tail-wheel airplanes.

So this has been Kalpana's life and times - a truly remarkable journey. A journey which started in Karnal, wended its way to the US where she equipped herself with skills to enter the race to space and then, made it there - not once, but twice. She was a small town girl who dreamt big and then, had the self-belief to chase that dream half way across the world. She caught up with that dream and then lived it. Indeed, she died while living that dream. I believe that Kalpana personified the Power of Imagination, and hence the title of this presentation. She imagined and therefore she was!

Moving on now to the Mission itself:

Mission Background

Crew of 7

The seven member crew assigned to STS-107, from left to right, were:

David Brown - Mission Specialist: 46 year old Captain in the US Navy, a naval aviator and navy flight surgeon. Worked on Laminaroot soot processes and structure of flame balls experiment.

Rick Husband - Commander; 45 year old Test Pilot; Colonel in USAF, a veteran of STS-96. Was working on European Research in Space and Terrestrial Osteoporosis and Shuttle Ozone Limb sounding experiment.

Laurel Clark - Mission Specialist; 41 year old Commander and Captain select in the US Navy and a naval flight surgeon. Worked on Sleep wake actigraphy and Vapor Compression Distillation Experiment.

Kalpana Chawla - Flight Engineer and Mission Specialist; 41 year old Aerospace Engineer and FAA certified Flight Instructor, veteran of STS-87. Worked with experiments on Astroculture, Advanced Protein Crystal Facility

Michael Anderson - Payload Commander and Mission Specialist; 43-year-old Lt Col in the USAF, former instructor pilot and veteran of STS-89. Worked on Water Mist Fire Suppression and structure of flame balls.

William McCool - Pilot; 41 year old Test Pilot; Commander in the US Navy. Worked on Advanced Respiratory Monitoring System, Biopack and Mediterranean Israeli Dust Experiment.

Ilan Ramon - Payload specialist; 48 year old fighter pilot in the Israeli Air Force and Israel’s first astronaut. Worked on Mediterranean Israeli Dust Experiment.
No Special Requirements

No rendezvous; EVA; No Manipulator Arm work.

Two Teams

Two teams were formed - Red and Blue- to support a 24-hour work cycle. Kalpana was assigned to the Red team.

Mission Training

The crew trained singly and together for 4811 hours. In addition, a total of 3500 hrs were devoted to payload specific training.

Simulator

Simulator sessions began in Apr 2002 and were attended by all members of the 7 member crew.

Reviews

A launch Readiness Review was done on 18 Dec 2002, about a month before the launch. Here, the review board checked if the Flight Preparation Process Plan was fully acted upon.

This was followed by a Flight Readiness review, which provided a summary of the certification, and verification of the shuttle vehicle, flight crew and payloads and, in this review, the rationales for the acceptance of residual risk was reviewed. The final flight readiness review was held on 09 Jan 2003, a week before launch.

Weather

On the day of the launch, 16 Jan 2003 the weather was just right: RH 68%; Calm winds; Scattered clouds at 4000 ft; visibility 11 km.

The crew moved into the shuttle and took their places for the launch as the countdown progressed normally.

The Accident

Physical Cause

The physical cause of the loss of Columbia and its crew was a breach in the Thermal Protection System on the leading edge of the left wing, caused by a piece of insulating foam which had separated from the left bipod ramp section of the external tank, 81.7 seconds into the launch sequence. This piece then struck the wing in the vicinity of the lower half of the reinforced Carbon-Carbon panel in the lower half of the LH wing’s leading edge.

During re-entry, this breach in the thermal Protection System allowed superheated air to penetrate through the leading edge insulation and progressively melt the aluminium structure of the left wing. This resulted in a weakening of the structure, which buckled later, under increasing aerodynamic loads causing loss of control, failure of the wing and consequent break up of the shuttle orbiter. This happened in a flight regime in which, given the current design of the orbiter, there was no possibility of the crew to survive.

Photographic Evidence

Post launch photographic analysis showed that one large piece and at least two smaller pieces of insulating foam separated from the external tank area at 81.7 sec after launch. Later analysis showed that the larger piece, measuring some 27 inches long and 18 inches wide, struck Columbia on the underside of the left wing at 81.9 sec into the launch sequence.

De-Orbit Burn and Re-Entry Events

At 2:30 am on Feb 1 this year, the Flight Control Team at Mission Control, was unaware of the events that were going to happen on that fateful day. The team was not working on any issues or problems related to the planned de-orbit and re-entry of Columbia. Significantly, the team indicated no concerns about the debris impact on the left wing during the launch sequence. They treated the re-entry like any other. Peace prevailed in Mission control - it was business as usual.

Landing Conditions: With help of weather forecasters and pilots in the shuttle training aircraft, it was determined that weather conditions were ideal for landing at the Kennedy Space Centre. At 8 am that morning, the Mission Control Flight Director polled the heads of various system groups, seeking a Go/No Go decision from each of them. And so, 20 minutes before the scheduled de-orbit burn time, a 'Go' was given to the Mission Commander for start of the re-entry sequence.

EI + 270 sec: Early Interface or EI is defined as the point at which the Orbiter first encounters discernible atmosphere. Typically this arbitrary point is placed at an altitude of 400,000 ft. The re-entry sequence clock is zeroed at this point and it reads EI + 000 secs.
At EI + 270 secs a sensor in the left leading edge spar showed a higher than normal strain. This fact was recorded only on the on-board recording system. It was not telemetered either to ground controllers or displayed to the crew on board.

EI + 404 sec: Columbia enters a 10 min period of peak heating during which thermal stresses build up to a maximum. Columbia was doing M 24.1 at this stage.

EI + 577 sec: Slowing down to M 23.0, at 231,000 ft, the wing leading edge temperatures had reached 2800 deg F. The shuttle was crossing over California when the superheated air around it suddenly brightened, causing a noticeable streak in the orbiter’s luminescent trail. This event repeated four times in the ensuing 23 seconds and was picked up by witnesses on the ground. The shuttle had started disintegrating.

EI + 614 sec: The Orbiter crossed into Nevada airspace, now traveling at M 22.5 while flying 227,400 ft up. Witnesses observed a bright flash and 18 similar events, as Columbia streaked over Utah, Arizona, New Mexico and Texas. In Mission Control, the re-entry appeared normal till this time. Hereafter wing leading edge temperatures reached 3000 deg F. Four hydraulic sensors started reading off scale, low. This was the beginning of the end.

Last Call: At EI + 831 sec, a broken call was heard from the Commander which went like, "And... uh.... Hou....". This was shortly after telemetry reported loss of all three hydraulic systems.

At EI + 923 sec, M 18.1, 200,700 ft., Mission Control heard the last call from Columbia’s Commander. It just went, "Roger....." and the transmission got cut off in mid-word. Telemetry data was lost at this point but it was assumed that this happened because the Shuttle’s antennas were being switched at that time.

Post flight video and image analyses indicated that bright flashes suddenly enveloped the Orbiter followed by a dramatic change in the trail of superheated air at EI + 969 sec. This was considered as the most likely time of the main break up of Columbia.

Having failed to re-establish VHF contact again with the Orbiter, the Flight Director, as per established procedure, ordered closure of the doors of Mission Control an hour and nine minutes after clearing the de-orbit burn. This was done to facilitate investigation of the loss of Columbia and the seven astronauts on Board.

The Analysis

ET Thermal Prot System

The external tank was coated with two different materials: one a dense composite ablator for dissipating heat and another, a low-density closed cell foam for high insulation efficiency. Taken together, the Thermal Protection System was designed to maintain an interior temperature that kept the oxygen and hydrogen in a liquid state and also maintain the temperature of the external parts high enough to prevent frost and ice from forming on it. Pre-existing defects in the foam insulation system caused the weakness and break away of a piece during launch.

Damage Assessment

This piece of foam was imparted a rotation of some 18 revs per second by the flow field and it impacted the leading edge of the left wing at a relative velocity of around 750 ft/sec. The impact generated a cloud of pulverized debris with a very small component of velocity away from the wing. It was no glancing blow.

Loss of Control

As a result of the gaping gash in the LH wing’s leading edge, superheated air and plasma entered the confines of the wing assembly and progressive failures started to occur within the structure.

The control system started applying needed corrective inputs. A positive roll and a negative yaw input was recorded as a result of increasing drag due to progressive failure of the LH wing. The flight control system attempted to compensate for the increased left yaw by firing all four right yaw thrusters. Even with all four thrusters firing along with maximum rate of change of aileron trim, control was lost at EI + 970 secs - 47 seconds after the Commander’s last call which had got cut off in mid-word.

Crew Module

The crew module suffered a thermal degradation of structural properties. This resulted in a rapid, catastrophic sequential structural breakdown rather than an instantaneous explosive failure. The destruction of the crew module took place over a period of 24 seconds, starting at an altitude of 140,000 ft and ending at 105,000 ft.

Surprisingly, videos of crew during re-entry show that prescribed procedures for the use of pressure clothing was
not strictly adhered to. Three crewmembers were not wearing gloves while one was without a pressure helmet. This, of course, is merely of academic interest as the observation is irrelevant from the crew survivability standpoint.

The Learning

The investigation was thorough and exhaustive. The Board expanded its brief and decided to go beyond the accident and look at the entire occurrence at Programme Managerial level. They felt that factors leading to the accident went beyond physical mechanisms. This is the insight we need to obtain from the loss of Columbia. This needs to be our learning from it because we are yet new in the business of running complex projects. We need to heed these messages because all projects, no matter how well run they are by very well meaning managers, will continue to be susceptible to such failures. We need to guard against the factors I shall be covering now.

Schedule Pressures

NASA could not obtain budget increases through the 1990s. Rather than adjust its ambitions in response to this new state of affairs, it continued to push an ambitious agenda of space science and exploration, including a costly Space Station Program. If NASA wanted to carry out that agenda, its only recourse, given its budget allocation, was to become more efficient, accomplishing more at less cost. The search for cost reduction solutions led top NASA leaders to downsize the Shuttle workforce and, outsource various Shuttle Program responsibilities, including safety oversight.

Additionally, another factor influenced the decisions that led to the accident. Driven by the need to service the International Space Station, the Shuttle's increasing flight rate created enormous schedule pressure. This resulted in compression of training schedules, shortage of spare parts, and the focusing of resources on near-term problems. The Board observed that NASA managers "may have forgotten - partly because of past successes, partly because of their own well-nurtured image of the program - that the Shuttle was still in a research and development phase."

Communication

The Mission Management Team overlooked 8 opportunities to request for additional video footage of the launch from other sources. In so doing, they missed out on the chance of taking contingency measures. Managers viewed the need for in-orbit imagery for damage assessment, as a non-critical engineering desire rather than a critical operational need. While this may not have saved the vehicle, it perhaps would have increased the chances of crew survival. Mostly, this was, due to communication failures within the team.

Decision Making

Decision-making was flawed. Numerous warning signs that were there of the impending disaster, were over looked. They started living with the possibility of foam strikes, taking comfort from the fact that craft were returning back despite loosing foam on almost every launch. Foam debris losses that violated design requirements came to be defined by NASA management as an acceptable aspect of Shuttle missions - one that posed merely maintenance "turnaround "problem rather than a safety-of-flight concern. In fact, their management techniques unknowingly imposed barriers that kept at bay both engineering concerns and dissent views and, ultimately, helped create "blind spots " that prevented them from seeing the danger posed by foam strikes.

Culture

The Board found out that Peoples' actions are influenced by the Organization in which they work, shaping their choices in directions that even they may not realize.

In all official engineering analyses and launch recommendations prior to both the Challenger and Columbia accidents, evidence that the design was not performing as expected was reinterpreted as acceptable and non-deviant. This, diminished perceptions of risk throughout the Agency. The first time such a thing is done, becomes the turning point. It establishes a precedent for accepting, rather than eliminating, these technical deviations. Engineers and managers incorporated worsening anomalies into the engineering experience base, which then functioned as an elastic waistband, expanding to hold larger and larger deviations from the original design. Anomalies that did not lead to catastrophic failure were treated as a source of valid engineering data that justified further flights! Rings a bell?

The work culture at NASA did not countenance dissent. It is obvious but worth acknowledging that people who are marginal and powerless in Organizations, may have useful information or opinions that they don't ex-
because particular, this demise, dent views believe, that Challenger's O-ring failure. This other of failure. with high-risk minination. of opening solo Program orbit to the shuttle. Managers in the Shuttle Program denied the Debris Assessment Team’s request. By so doing, they put that team in the untenable position of having to prove that a safety-of-flight issue existed without the very images that would permit such a determination. This is precisely the opposite of how an effective safety culture should be acting. Organizations that deal with high-risk operations must always have a healthy fear of failure. Operations must be proved safe, rather than the other way around. NASA inverted this burden of proof. This approach was followed earlier too and it resulted in Challenger’s O-ring failure.

Conclusions

So, is there a message for us in all this?

I hung up my flying boots, 33 years after I first went solo in an aircraft. During this time, I have flown and tested high performance aircraft for the IAF and HAL and so believe, that I have earned the right to share some of my views with my erstwhile colleagues.

During the condolence meeting led by the Vice President of India in Parliament House, to mourn Kalpana’s demise, I had remarked that Kalpana and her crew mates would not have died in vain. I explained that as a result of this accident Space Flight in general and Shuttle flights in particular, would become safer. I said this at that time because that was what needed to be said then.

Today is different. We are in an in-house session where all of us are or were in the business of flight research and development and, as part of this activity, constantly engaged in path breaking work.

I did not mean what I said on that day in Parliament House. I was being magnanimous. I believe that the NASA team looking after STS 107, had failed in its duty. The Space Shuttle Program managers failed to fulfill the implicit contract: to do whatever is possible to ensure the safety of the crew. To learn from an accident is essential and must be done, but this does not absolve any of those Managers from the blame of failing the Mission and the Crew. This is an aspect that has been glossed over by the Columbia Accident Investigation Board.

If, as Managers, we are given the onerous responsibility of running prohibitively expensive projects of great National importance, then, failure must cease to be an option. We need to learn from others’ failures and be circumspect ourselves. We need to make haste, surely; but slowly. Sure, failures may yet happen, such is the nature of the beast of exploration but we certainly cannot afford ’Failures of Foresight’, as was the case in respect of Columbia. We need to look deep and hard at all the aspects that collude to increase Programme pressures. It is imperative that we do not mix technology with politics - I mean the politics of Programme Management. We have a great bunch of Aerospace professionals. We need to give them the space to do their stuff.

We owe this to our fraternity; we owe this to our profession; we owe it to our Nation and last, but certainly not the least, we owe it to Kalpana Chawla who, along with her 6 colleagues, sat strapped in a seat, a mute spectator, as her illustrious career and remarkable life was snuffed out while her craft disintegrated over a foreign land - just because her Program Managers needed to look good in front of a System which rewards pushiness and short cuts.

If we do not learn from her tragic experience, then yes, she would certainly have died in vain.