3. CONCLUSIONS

3.1 Findings

1. The flightcrew was certificated and qualified for the flight and the airplane was dispatched in accordance with company procedures and Federal regulations.

2. Weather was not a factor in this accident.

3. Air Traffic Control services were supportive of the flightcrew and were not a factor in the accident.

4. The airplane experienced an uncontained failure of the No. 2 engine stage 1 fan rotor disk assembly.

5. No. 2 engine fragments severed the No. 1 and No. 3 hydraulic system lines, and the forces of the engine failure fractured the No. 2 hydraulic system, rendering the airplane's three hydraulic-powered flight control systems inoperative. Typical of all wide-body design transport airplanes, there are no alternative power sources for the flight control systems.

6. The airplane was marginally flyable using asymmetrical thrust from engines No. 1 and 3 after the loss of all conventional flight control systems; however, a safe landing was virtually impossible.

7. The airport emergency response was timely and initially effective; however, cornstalks on the airfield and the failure of the Kovatch P-18 water supply vehicle adversely affected firefighting operations.

8. The FAA has not adequately addressed the issue of infant occupant protection. The FAA has permitted small children and infants to be held or restrained by use of seatbelts during turbulence, landing, and takeoff, posing a danger to themselves and others.

9. *Separation of the titanium alloy stage 1 fan rotor disk was the result of a fatigue crack that initiated from a type 1 hard alpha metallurgical defect on the surface of the disk bore.*

10. *The hard alpha metallurgical defect was formed in the titanium alloy material during manufacture of the ingot from which the disk was forged.*

11. *The hard alpha metallurgical defect was not detected by ultrasonic and macroetch inspections performed by General Electric Aircraft Engines during the manufacturing process of the disk.*

12. *The metallurgical flaw that formed during initial manufacture of the titanium alloy would have been apparent if the part had been macroetch inspected in its final part shape.*

13. *The cavity associated with the hard alpha metallurgical defect was created during the final machining and/or shot peening at the time of GEAE's manufacture of the disk, after GEAE's ultrasonic and macroetch manufacturing inspections.*

14. *The hard alpha defect area cracked with the application of stress during the disk's initial exposures to full thrust engine power conditions and the crack grew until it entered material unaffected by the hard alpha defect.*

15. *General Electric Aircraft Engines material and production records relevant to CF6-6 stage 1 fan disk S/N MP0 00385, which was the failed disk, were incomplete.*

16. *Regarding the existence at General Electric Aircraft Engines of two S/N MP0 00385 disks, an outside laboratory had possession of the disk, which was rejected for an ultrasonic indication at the time that the disk that eventually separated was receiving its final processing on the production line. Therefore, the two S/N MP0 00385 disks were not switched at the manufacturing facility.*

17. *General Electric Aircraft Engines disk manufacturing records and associated vendor-supplied documents, together with the system for maintaining and auditing them, did not assure accurate traceability of turbine engine rotating components.*

18. *United Airlines fan disk maintenance records indicated that maintenance, inspection, and repair of the CF6-6 fan disk was in accordance with the Federal Aviation Administration-approved United Airlines' maintenance program and the General Electric Aircraft Engines' shop manual.*

19. A detectable fatigue crack about 0.5 inch long at the surface of the stage 1 fan disk bore of the No. 2 engine existed at the time of the most recent United Airlines inspection in April 1988 but was not detected before the accident.

20. The discoloration noted on the surface of the fatigue crack was created during the FPI process performed by UAL 760 cycles prior to the accident, and the discolored area marks the size of the crack at the time of this inspection.

21. The inspection parameters established in the United Airlines maintenance program, the United Airlines Engineering Inspection Document, and the General Electric Aircraft Engines shop manual inspection procedures, if properly followed at the maintenance facility, are adequate to identify unserviceable rotating parts prior to an in-service failure.

3.2 Probable Cause

The National Transportation Safety Board determines that the probable cause of this accident was the inadequate consideration given to human factors limitations in the inspection and quality control procedures used by United Airlines' engine overhaul facility which resulted in the failure to detect a fatigue crack originating from a previously undetected metallurgical defect located in a critical area of the stage 1 fan disk that was manufactured by General Electric Aircraft Engines. The subsequent catastrophic disintegration of the disk resulted in the liberation of debris in a pattern of distribution and with energy levels that exceeded the level of protection provided by design features of the hydraulic systems that operate the DC-10's flight controls.