APPENDIX A
OPERATIONAL RISK ASSESSMENT & MITIGATION STRATEGIES

RAF has undertaken an evaluation of the safety risk for DC3. The conclusions of the safety evaluation have also been discussed by the RAF Safety Committee. Whereas the primary target for DC3 is isolated thunderstorms, it is important to note that more complicated cloud systems can be expected; i.e., that hazards associated with neighboring storms may impact the aircraft while focusing on the target storm. It is also important to note that these storms may develop rapidly, thus a maneuver that can safely be executed early in the life-cycle of a storm may be hazardous at a later time. The following analysis is general in nature, but actual flight maneuvers are -- as always -- subject to pilot's approval.

(1) Airborne Mission Coordinator/Ground-based Aircraft Coordinator
Targeting deep convective clouds will need to be done with great care. RAF will provide a dedicated mission coordinator on the GV, who must be experienced in airborne sampling near storms. The task of this person is to be a resource for the onboard mission scientists and the pilots. His/her main responsibilities will include keeping a constant eye on the development of the weather during the flight, coordinating mission needs within the pilots' operating constraints and ATC clearances, and requests for clearance modifications. The mission coordinator will, while flying on the aircraft, have access to ground based, remote sensing and aircraft in situ sampled data and interpretation from a ground based EOL aircraft coordinator. The airborne mission coordinator will routinely examine (lower-resolution, less frequently updated) satellite images, radar images, lightning maps, the three-directional, visual (camera) view, GV weather radar display, and aircraft science measurements to evaluate the hazards surrounding the aircraft. To help with this task, a customized rack has been included in the payload that will allow the mission coordinator access to as much information as possible to provide situational awareness.

The airborne mission coordinator will be in close contact with the ground coordinator. The main task of the ground coordinator is to examine satellite images, radar images, ground-based observations, lightning maps, and other high-bandwidth sources of data on a continuous basis and to advise the aircraft of potential hazards. This person will be a resource for the project personnel on the ground and the airborne mission coordinator (s), by implementing EOL (and other) data products designed to assist real time flight decision making. The ground coordinator should be scheduled for practice operations prior to the field deployment.

The mission coordinator and the ground-based coordinator will participate with the flight crew in pre-project planning and in the development of airborne support data products. The Mission Coordinator will conduct a daily mission briefing of the aircrew prior to takeoff. The briefing will focus on the expectation of the severity of the convection, based on available forecasts and soundings (Convective Available Potential Energy, CAPE, and vertical wind shear evaluation from hodographs).

Communication onboard the aircraft will take place as follows: The Science PI will make requests to the Mission Coordinator, who will then communicate the request to the pilots.

(2) Hazards

Hail, turbulence and microburst, wind shear, lightning and aircraft icing were identified as hazards by RAF staff, which are all associated with damage to the aircraft, injury to onboard personnel, and disruption to research. The following lists the mitigation strategies that EOL will implement for safe aircraft operations:

Hail: The aircraft will not be flown in hail or graupel. Hail can cause catastrophic damage to the aircraft and medium density graupel will erode the paint and radome of the aircraft. To avoid hail encounters, which can come from above the flight level, the aircraft must remain a safe distance away from the main cell associated with large storms. For severe storms, such as supercell storms, this distance can be as great as 20 miles or more separation from the boundaries of the main cell (for example by reference to the 40 dBZ or greater counter, which is the approximate red boundary of the onboard weather radar). A 20-mile distance is required for the GV to make a 3-minute 180-degree turn at high altitudes. Avoidance of graupel will require avoidance of cellular deep convection with tops colder than approximately -10 C. This does not preclude sampling in the stratiform anvil region, provided adequate separation from the main storm is achieved. Since the anvil from major storms extends many tens of miles downwind of the storms, this should not preclude the major objectives of DC3. In deep convection large, damaging hail may occur in very low concentrations, that is, a low radar reflectivity is not necessarily indicative of safe flying conditions. For instance, flying below the so-called “weak echo region” in supercell thunderstorms has previously led to severe damage to NSF/NCAR aircraft (Queen Air incident in CCOPE, 1981). To minimize the risk in DC3, the GV aircraft will not be flown below active updraft regions; rather that examining “updraft regions” the DC3 objective can be achieved by flying in the boundary-layer “inflow regions” before this air moves in under the cloud and is accelerated upwards. This inflow region is typically on the southeast side of the storm. We believe that the inflow region can usually be identified adequately so that it can be sampled with adequate separation from the main cell, so the objectives of DC3 can be achieved.

Turbulence and microbursts: The GV is rated to routinely handle turbulent events of 2.5g before it must undergo a field inspection to check for cracks. Strong turbulence is usually associated with most regions in, near, or immediately downwind of strong convective cores. Our procedures for maintaining separation from these cores to mitigate the hail and graupel hazard should also provide separation from this turbulence hazard. However, under some circumstances, such as the presence of a strong mid or upper tropospheric jet, enhanced turbulence may be present even well-downwind of the storms. Under these conditions, special care will be given to avoidance of certain flight levels and the near-storm environment where these conditions are likely to exist.

The gust-front is normally apparent from visual inspection (provided the GV is not flying in precipitation) and from radar information, thus intentional or unintentional penetration of the gust front is not expected to occur, especially since the project data will facilitate avoidance of this region.

Microbursts may occur under precipitating convective clouds, but this is usually only a danger during take-off and landing. For DC3 the risk can be mitigated by flying at sufficient speed at low altitude, and by avoiding low-level flight close to precipitating cumuli.

Lightning: Deep convection is almost always associated with electric charge, thus lightning in the DC3 study storms is expected to be frequent. The GV is designed to withstand occasional lightning, although normal operation of these aircraft is to avoid lightning regions. Lightning strikes may lead to damage to the skin of the aircraft or the external instruments, e.g., significant “welding spots” where the lightning exits the aircraft. The science payload as part of DC3 is less likely to be hardened against lightning strikes, thus catastrophic damage to the science payload is a possibility if a lightning strike should occur.

In order to mitigate the risks associated with lightning, RAF has installed a lightning-mapping system with display capability as part of the standard aircraft weather-avoidance radar display. This display capability will be extended to the mission coordinator station. In addition the intent is to access the National Lightning Detection Network (NLDN) and other project lightning information via satellite communications.

Several of the DC3 objectives are closely linked to lightning, and can only be accomplished by accepting some risk of lightning strikes, however, normal aircraft summertime commercial flights also accept some risk of lightning strikes. We feel this is an acceptable risk, provided that risk mitigation steps are taken to avoid regions where lightning is expected. Given the availability of ground lightning data to the aircrew and the onboard lightning detection system, we feel the aircraft will be better equipped to identify hazardous lightning regions than most commercial aircraft.

Sampling of the stratiform anvil region of the storm is an essential feature of DC3. We believe this can be safely accommodated provided:

- Adequate separation from the main convective core of the storm is maintained to avoid, hail, graupel, and turbulence. While this distance is somewhat dependent on storm intensity and other characteristics (e.g., ambient wind speeds/wind shear), typically about 20 miles separation from the 40 dBZ contour of severe storm cells can be expected for midlatitude cells, provided no secondary cells are observed in or near the anvil region. RAF pilots will normally execute anvil sampling from the downwind edges to upwind, and will terminate sampling if moderate or greater turbulence, graupel, or lightning is encountered during sampling, regardless of the distance from the main cell.

- Areas of known lightning activity in the anvil are avoided. These will be identified as discussed above. This may preclude sampling of highly electrified anvils, but we believe that it will be unlikely for this situation to be the case for most of the anvil regions found in DC3.

Wind shear: Deep convection is often associated with regions of jet streams, and this may lead to sudden changes in the aircraft's speed relative to the surrounding air. Gravity waves may also be excited by the convective core impinging on the overlying inversion. When flying at high altitude, the GV envelope is quite narrow, and the risk exists for stalling the aircraft.

In order to mitigate the risk of wind shear, it will therefore be necessary to operate the GV at altitudes where there is a sufficient margin between the aircraft speed and the stall speeds. The implication is that the GV will not be able to reach maximum flight altitude until later in the flight when it is lighter, and that the maximum ceiling is likely to be 2 kft lower than during flight in more quiescent air.

Aircraft icing: While the project is not targeting areas of super cooled liquid water, it is likely that some intervals of significant icing of the airframe will occur during storm penetrations. The GV is well equipped to deal with such hazards but the aircraft are not designed to accommodate unusually severe icing, such as occurs in regions of super-cooled large droplets or in freezing rain. Super-cooled water may occur in both the lower and (more rarely) upper parts of the convective core of deep convection. These will not be penetrated during DC3. Lower-altitude feeder cells may contain significant amounts of super-cooled water, but these are of relatively limited extent and not particularly targeted by DC3. The anvils are expected to be mostly glaciated so the risk of aircraft icing problems is small when flying in the anvil.

The risk of aircraft icing will be mitigated by avoiding flight in extensive, high super-cooled liquid water regions. If encountered, the aircraft will exit these areas immediately to avoid dangerous ice buildup on unprotected areas of the airframe. Furthermore, at GV airspeeds (which produce compress ional heating of the air) the graupel avoidance mitigation procedures will also eliminate most icing encounters.

It is EOL's opinion that this safety feature will not be too restrictive to prohibit the project objectives from being achieved. EOL will work with the project PIs to develop reasonable flight plans and procedures to avoid these conditions. It should also be noted that most of the GV and C-130 instrumentation has provision for anti-icing, but measurement quality may nevertheless suffer in extended regions of super-cooled liquid water.