UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Guidelines for Low-level Geophysical Surveying with Fixed-wing Aircraft

by

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GUIDELINES FOR LOW-LEVEL GEOPHYSICAL SURVEYING WITH FIXED-WING AIRCRAFT

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ABSTRACT

Many airborne geophysical surveys must be flown at less than 500 ft (150 m) above ground level, and in order to conduct the surveys, the aircraft must be modified by adding equipment. Adding external sensing apparatus to the aircraft may make the surveys more risky because the added equipment increases aerodynamic drag and reduces stability and control. To minimize the risk, (1) the modified aircraft should be thoroughly flight tested to define its new operating envelope, (2) the pilot and crew should work together and understand the limitations and dangers of the survey, and (3) pilot and crew should carefully plan such things as flight patterns that will avoid dangerous maneuvering and pay strict attention to safety-of-flight considerations such as airspeed, altitude, obstacles, and other hazards.

INTRODUCTION

Airborne geophysical surveying began in earnest after World War II and continued into the 1950's, when surveying teams flew light aircraft with hand-held scintillometers searching for uranium deposits. Today, geophysical surveying has become an even more important source of geological data, but because many of these flights must fly slowly at or below 500 ft (150 m) above the ground, and because adding the equipment needed for the surveying makes the planes more difficult to control, low-level surveying can be risky.

Geoscientist and pilots who are planning to conduct (or even those who may already conduct) low-level geophysical surveys with fixed-wing aircraft may not always be able to make a thorough technical evaluation of the problems, procedures, and dangers involved in such flights. This report presents some useful information about these problems, procedures, and dangers; and the report suggests some general guidelines when testing a plane before a flight, when planning a flight, and when the survey crew is actually flying.

Most often, surveys flown at less than 500 ft (150 m) above the ground either follow the terrain or maintain a constant barometric-pressure altitude. Surveys range from meandering flights that simply provide a platform for observers or photographers to complicated flights that carry sophisticated on-board sensors and instrumentation over tight grids at precise levels. As a general rule, the more sophisticated the mission and on-board equipment, the more critical and rigid the flight parameters.

This report presents information that the geoscientist or pilot, who is just beginning geophysical surveying, may find useful. The report is laid out along these lines: first, it provides general information that describes problems caused by adding surveying equipment to planes not designed for such modifications; and second, it reminds pilots of some of the regulations and dangers that are unique to low-level, low-speed geophysical surveying. Throughout the report, the purpose is to suggest some general procedures for reducing the dangers and problems of low-level airborne geophysical surveys.

FLIGHT TESTING MODIFIED AIRCRAFT

Adding equipment such as airborne gamma-ray spectrometers, electromagnetic equipment, air particulate samplers, infrared and ultraviolet scanners, radar, and other kinds of apparatus for a variety of geophysical and environmental monitoring applications means that aircraft are modified in ways that change the way they fly; and since the equipment may work best at low speeds and low altitudes, the aircraft and crew need to assess the problems caused by the equipment. Safely modifying the aircraft may require tests that are as simple as verifying airworthiness with a single test flight or as complex as having engineers test the aircraft by considering it an experimental prototype with unknown and untested flight characteristics. Most often, however, installing external surveying equipment results in a situation somewhere in between, so no specific test program can be prescribed here.

To determine the airworthiness of an aircraft, the program should test all flight maneuvers that might mean a serious degradation of flying qualities and performance. Testing should determine suitability--how well the modified aircraft is suited to its mission--by comparing and contrasting the modified and unmodified aircraft's flight envelopes and characteristics, and by thoroughly investigating any tendencies for the modified aircraft to be less controllable. The need for a trained and qualified test pilot for this activity cannot be overemphasized. Governmental agencies responsible for certifying the aircraft as airworthy may also require sufficient test data (for example, U.S. Federal Aviation Regulation (FAR) 21.25).

Once deemed airworthy, the plane is then tested for its suitability as an instrument platform. Tests for suitability must determine whether potential problems, such as the following, may prove either dangerous to the crew or prove detrimental to the scientific data: aircraft-generated electrical interferences, mutual or unidirectional interferences between the aircraft and the scientific systems, or the possible problems caused by aerodynamic accelerations, turbulence, and vibrations on the aircraft. Finally, operational procedures will need to be established and tested. These various tests suggest a test-plan hierarchy that logically progresses through two distinct phases:

1. the aircraft as an experimental prototype.
2. the aircraft as an equipment test bed.

THE AIRCRAFT AS AN EXPERIMENTAL PROTOTYPE

The performance and flying qualities of an aircraft are directly related to the aerodynamic forces and moments acting upon it (Dommasch and others, 1967; Dickinson, 1968). When external equipment is added to the airframe, some degradation of flying qualities and performance is expected and is, within limits, acceptable. The loss of flying qualities such as stability or control (due, for example, to deflection of airflow over control surfaces) becomes critical by imposing an excessive work load on the pilot. The loss of performance (due, for example, to increased form drag) during in-flight emergencies, such as when twin-engine aircraft lose power in one engine, is a crucial safety consideration--obviously even more dangerous at low levels because the time to respond to these emergencies is limited. Thus, any modified aircraft should be considered a prototype and a flight test program designed accordingly.

Flying Qualities

The phrase "flying qualities" includes aircraft stability, control, and handling (fig. 1). Federal aviation regulations (and military specifications) require flying qualities tests during the manufacturer's certification program to ensure that an aircraft certified for use can be flown without exceptional piloting skill, strength, alertness, or special knowledge. Thus, all certified aircraft must fly the same way by regulation (Roberts, 1981; U.S. Air Force, 1980a; Fig. 1).

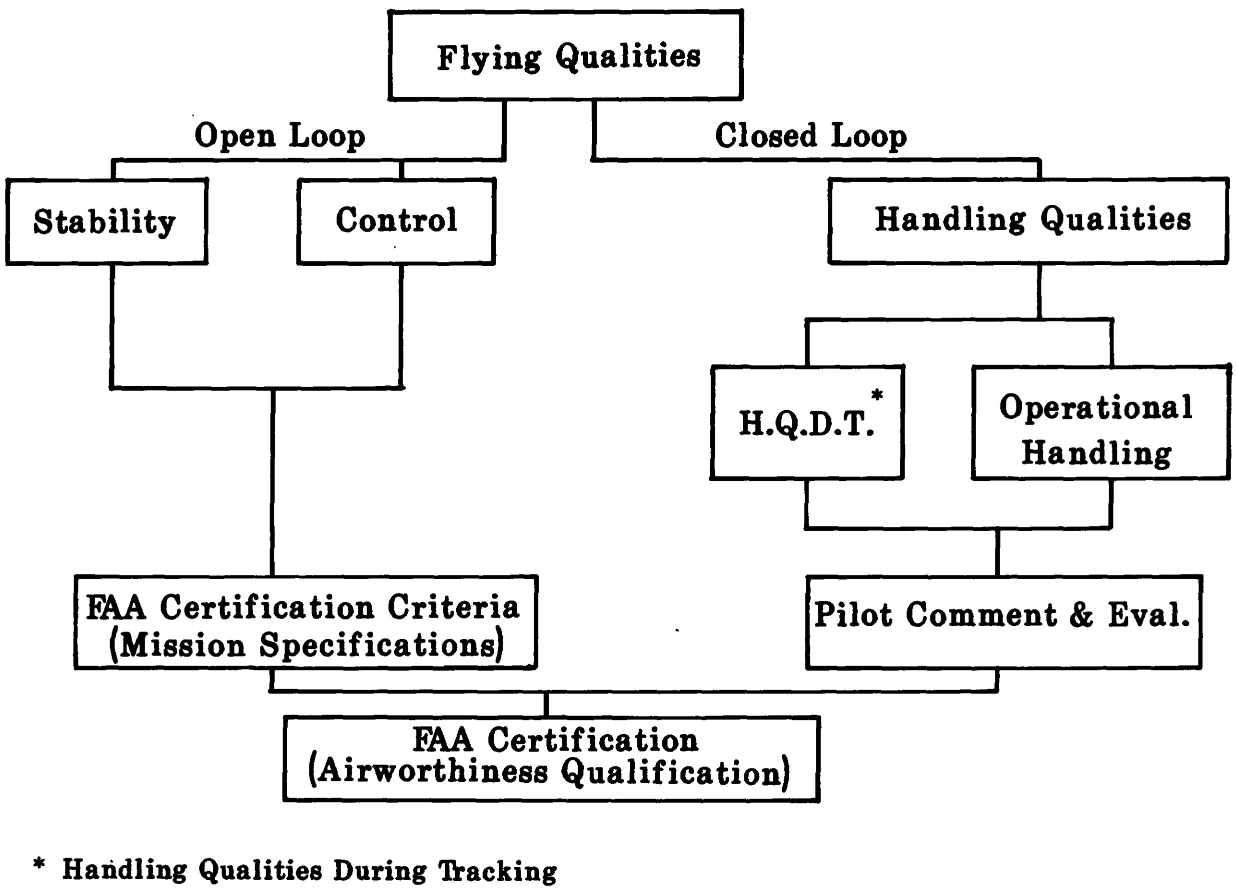

Figure 1.--Breakdown of flying qualities. Open loop refers to aircraft stability and control without the pilot manipulating the controls (controls free or fixed), and closed loop refers to aircraft handling qualities with the pilot making control inputs. Modified slightly from Roberts, (1981).

Stability.--Stability of an aircraft is a broad term that refers to both the initial tendency of the aircraft to return to the trim condition (called static stability) and the span of time between when an aircraft is disturbed from a trimmed flight condition and the controls are released (called dynamic stability). An aircraft is in trim when all forces and moments are in equilibrium; that is, total lift equals weight, thrust equals drag, and the total aerodynamic moments in pitch, roll, and yaw about the center of gravity c.g.) are equal to zero. Since it is difficult to quantify static stability directly in an aircraft, flight tests measuring static stability must be designed so that they determine the moments generated by the controls to hold the aircraft from the trim condition. These moments are equal to and opposite to the aircraft moments at work to return the aircraft to the trim condition. Dynamic stability is related to the magnitude of the static stability, the moment of inertia about the disturbed axis, and the aerodynamic damping of the aircraft components.

Control.--Aircraft controls are normally moveable trailing-edge flap devices that, when moved, vary the curvature (camber) of the aerodynamic surface to which they are attached, thereby inducing changes in local lift and generating unbalanced moments that maneuver the aircraft. All aircraft controls must enable the pilot, with limited applied force and movement, to maneuver the aircraft safely throughout its operating envelope and to recover from uncontrolled flight. Aircraft control tests should cautiously probe the areas of stability and control to verify their boundaries and the aircraft's flight characteristics.

Handling Qualities.--The handling qualities of the aircraft are determined by specifically defined operational tasks where the pilot evaluation of both system performance and pilot workload is critical. Handling qualities are initially determined qualitatively: most test pilots use the Cooper-Harper rating scale (fig. 2), but full spectrum stability and control testing may require more sophisticated tests in order to quantify the results properly. Handling Qualities During Tracking (HQDT) is a special USAF test technique to investigate closed (pilot-in-the-loop) loop system performance during precise tracking tasks. HQDT tests are done by perturbing the aircraft with high-frequency control inputs while flying a precise track such as a precision instrument approach to investigate any tendency toward pilot-induced oscillations.

Aircraft Performance

Aircraft performance is measured in terms of the interplay between wing and powerplant, with one additional factor: the passive forces of weight and air resistance must be overcome. Aircraft performance defines the aircraft's suitability for specific missions. However, because the external equipment adds weight and alters form, while the powerplant characteristics generally remain fixed, some performance loss in the aircraft should be anticipated. Regulations for minimum performance standards ensure safe take-off performance as well as minimum performance for multiengine aircraft with an inoperative engine (Roberts, 1980). The aerodynamic characteristics of the aircraft determine how much power and thrust are required, whereas the powerplant characteristics determine how much power and thrust are available for various conditions of flight (Hurt, 1965; U.S. Air Force, 1980b).

In geophysical surveying, aircraft may often be flown near the limits of their operating envelopes (fig. 3) and may therefore stall and sometimes spin. Spins are dangerous and unpredictable in most general aviation aircraft manufactured in the Unitd States, and the added surveying equipment could be responsible for totally unanticipated spin characteristics. Therefore, before flying the survey, the aircraft should be tested to make certain that it can recover from post-stall gyrations as well as incipient spins, with emphasis on establishing how to avoid spins entirely.

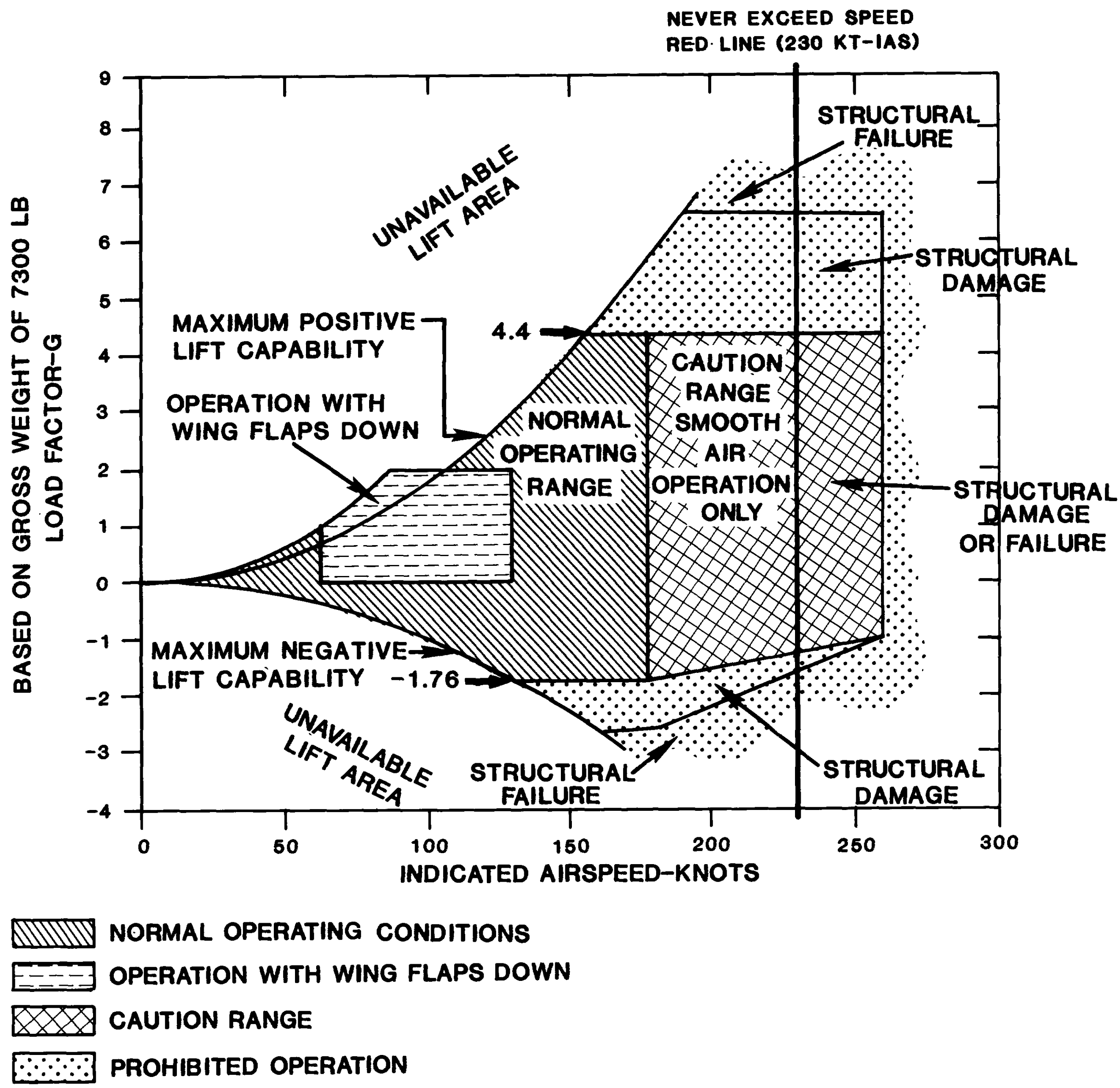

Figure 2.--An aircraft flight envelope using Army /Beech U8G as an example. It is also referred to as an n (or g) -V diagram. An aircraft's design strength limits are a function of airspeed and acceleration loading (g-force).

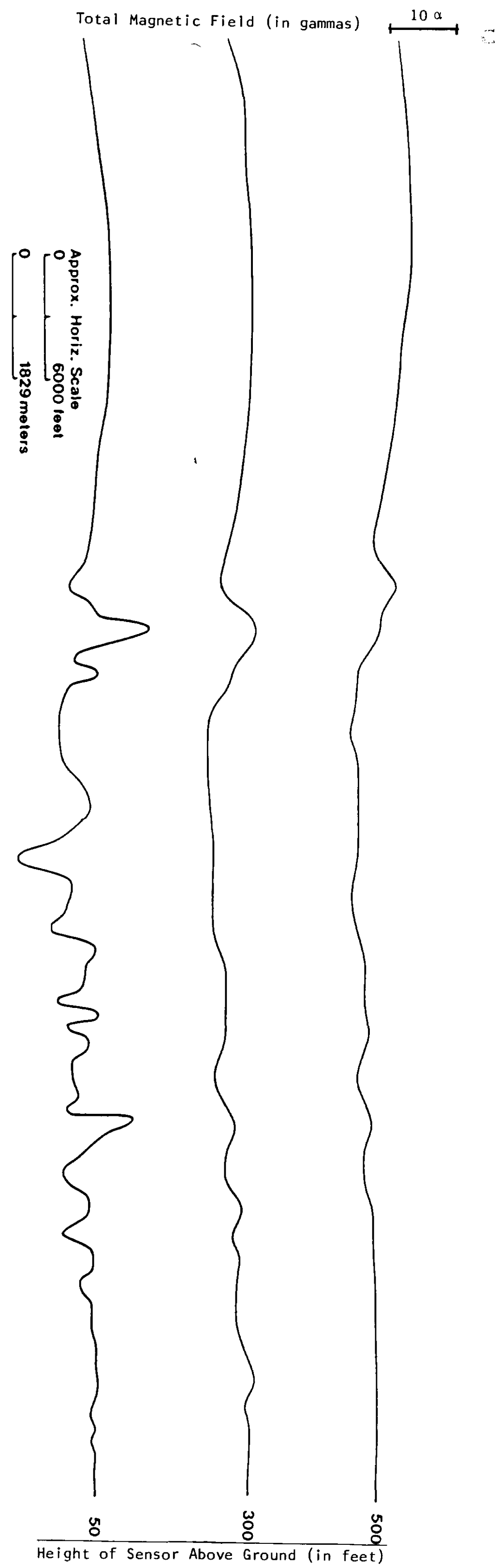

Figure 3.--Attenuation of high-wave number magnetic anomalies as a fuction of altitude. There is loss of information with increased altitude flown but safety is improved.

The aircraft type, nature of the modifications, its proposed mission, and flight envelope all combine to determine the maneuvers that are critical to test structural strength, integrity, and the ability of the plane to meet mission specificiations (Harse, 1972; Von der Heyden, 1972). Because design and preflight analysis do not always guarantee adequate strength, the aircraft must be flown through as much of the anticipated flight envelope as is possible--to verify its capabilities. (Since the aircraft was not designed for these modifications, the test pilot expects a reduced flight envelope.)

In some cases, special tests may be necessary because of the peculiarities of the appended apparatus itself. For example, it may be necessary to limit rotation and pitch angles during take off and landing with a tail stinger, or to limit bank angle during crosswind landing with wing-tip probes or antennae.

THE AIRCRAFT AS AN EQUIPMENT TEST BED

In most cases, factors such as gross weight, useable cabin volume, payload, structural strength, power and airspeed limits define the safety limits of equipment and crew load and also define the practical (safe) operational window. Some sensors (for example, gamma-ray spectrometers) are extremely sensitive to flight parameters such as airspeed and altitude (Darnley, 1972). For instance, accurate gamma-ray counting statistics require maximum detector volume and minimum ground speed and flight levels. Because of increased danger at low levels and low speeds, and because of the constraints imposed on detector volume by the aircraft available, an operational test program is generally required for any new equipment--to determine the optimum operational parameters for the systems at hand. This is a particularly pertinent requirement for experimental systems or new concepts (Donovan and others, 1975; Donovan and others, 1979; Donovan, 1981, p. 104-114). Such testing may become more elaborate than first envisioned primarily because it often unavoidably proceeds by trial and error.

Systems integration tests are usually needed to determine if there are any electrical interferences between the aircraft instruments and the scientific gear. The tests should sufficiently check for adequate electrical power supply, overheating, and altitude effects in unpressurized aircraft.

Any added appendages should also be closely monitored throughout the operating speed range of the aircraft for vibrations, sensor-induced control feedback, and flutter. Flutter is especially dangerous--particularly for flight tests (Federal Aviation Administration, 1979). Flutter can occur without warning and often results in sudden and catastrophic structural failure. The test pilot is faced with an emergency exit under less than optimum conditions (McCracken, 1972).

LOW-LEVEL SURVEYING--PRACTICAL CONCERNS

For the geophysicist, the ultimate concern of any airborne survey is the acquisition of good, useful data. But because geophysical surveying is often conducted close to the ground, the pilot and crew should be aware of the regulations and dangers unique to such low-level flights. In this section, practical concerns such as preflight planning, navagation, and procedures for maintaining acceptable line spacing, airspeed, and altitude are discussed.

Preflight Planning--Relevant Regulations

Regulations regarding minimum safe altitudes (FAR 91.79) were adopted many years ago specifically to safeguard life and property. Of the four sections in FAR 91.79, however, only (a), (b), and (c) are pertinent here, and pilots need to be familiar with them for both survey planning and execution. FAR 91.79(a) prohibits flying at altitudes that make it impossible to make "an emergency landing without undue hazard to persons or property on the surface". FAR 91.79(b) prohibits flying "over any congested area of a city, town, or settlement, ...[below] an altitude of 1,000 feet above the highest obstacle within a horizontal radius of 2,000 feet of the aircraft".

Perhaps of most interest to geophysical survey pilots is FAR 91.79(c), which prohibits flying below "an altitude of 500 feet above the surface, except over open water or sparsely populated areas." In that case, the aircraft may not be operated "closer than 500 feet to any person, vessel, vehicle, or structure." Since many geophysical flights are flown at low levels, pilots should be aware that the FAA sometimes waives FAR 91.79(b) and (c)--if such a waiver can be shown to be in the public interest. In the past, low-level geophysical surveys have received waivers of section 91.79(c) because they were determined to be in the public interest as exploration and research flights. To waive section (c), pilots must request a waiver by sending an FAA-provided form (7711-2) to the appropriate FAA Regional/District office. The pilot must also submit for FAA approval an Operations Manual containing this minimum information:

1. Area of Operation
   (a) Specific routes
   (b) Large area routes (operational area(s))
2. Certification/Equipment. (The aircraft used may be certificated in standard, limited, or restricted category, which may be dictated by the nature of the mission for which the aircraft is being used.)
3. Airworthiness. (The manual must describe the inspection program required by FAR Parts 91 and 43 for the aircraft operated as well as the administrative control and assignment of duties and responsibilities.)
4. Personnel. (The FAA has established minimum experience prerequisites for pilot personnel. In addition there are recurrency requirements.)
5. Flight Operations. (This section must contain information necessary to ensure compliance with the waiver.)

The Operations Manual, once approved by the FAA, serves as the primary assurance that persons on the surface will not be endangered; the FAA uses the manual as the basis for issuing a waiver. Violating the provisions of the manual means violating the terms of the waiver and can be justification for revoking the waiver. In addition, the FAA may, depending upon the type of operation involved, prescribe numerous and detailed special provisions.

One final note: if the survey aircraft will not be operated closer than 500 feet "to any person, vessel, vehicle, or structure," a waiver is not required as long as the pilot complies with FAR 91.79(a).

Navigation--Planning for Safety

Sophisticated navigational instruments (avionics) operating on a wide variety of principles are available: Very Low Frequency/Omega, Loran-C, Doppler Radar, Inertial Navigation System, are a few. Some kind of electronic navagational device is mandatory over water; over land, low-level surveys are most accurately positioned by using either a downward-looking film or video camera for flight path recovery. If a copilot is part of the crew, predetermined flight lines are drawn on a topographic map of appropriate scale, cut into suitably sized strips and rolled into scrolls. The copilot navigates from the strips, unrolling the scrolls as the flight progresses and course corrections are made as required. If a copilot/navigator is not on board the survey aircraft, a navigational chase aircraft can fly behind and slightly above the survey aircraft, providing navigation information to the survey pilot by radio if the mission is deemed particularly hazardous. In some instances, flagmen on the ground may be necessary for proper flight-line positioning. However, a competent, experienced pilot can usually navigate visually with adequate precision in most areas.

In preparing for the survey flight, the crew should consider three options. First, while drawing the flight lines on the map strips, the pilot and other members of the survey flight should note obstacles and terrain elevation. Often, new manmade obstacles may not be charted on dated topographic maps; current aeronautical charts should also be consulted, and even they may not contain the latest obstacle information. Second, in many instances, a preliminary reconnaissance flight in a light aircraft may be useful--to check for obstacles. Third, Military Training Routes (MTR) and Military Operations Areas (MOA) boundaries and block altitudes are depicted on sectional aeronautical charts and Low Altitude IFR charts. Military organizations schedule block times with FAA Flight Service Stations (FSS) for use of specific MTR's. Military pilots notify the FSS of the proposed route, entry/exit points, and flight times. Survey pilots can check the scheduled military block times prior to take off by telephoning the nearest FSS, who will also have information on MOA activity.

PROCEDURES FOR FLYING THE SURVEY

The critical parameters in actually flying a low-level survey are maintaining acceptable airspeeds, altitudes, and line spacing. Although techniques and limits vary with mission types and objectives, in general, heading should be held to $\pm 1^{o}$, and desired airspeed and altitude tolerances are ±2 knots and ±20 feet (3.7 km/hr and 6.1 m). In practice airsped and altitude tolerances may extend to ±5 knots and ±40 feet (9.2 km/hr and 12.2 m), owing to external factors such as turbulence and wind gusts. Mission dictated tolerances may, in turn, dictate environmental limitations beyond which it is pointless to fly.

To maintain airspeed and altitude control, the pilot can use a modified attitude instrument flying technique, which involves visually checking pitch and roll against outside references, and then cross checking with the airspeed indicator, altimeter, and attitude indicator. In fact, by keeping the attitude of the aircraft relative to the outside horizon, the pilot can also correct deviations in pitch and roll before the pitch and roll can even register on the instruments. The pilot can maintain a trim airspeed by adjusting power (usually with constant RPM and throttle/thrust lever adjustments) to a setting that either the pilot's experience or the test flights have shown will yield approximately the desired airspeed. This trim speed is then held constant with elevator control; however, because the power setting necessary to maintain the desired speed is only approximate, a slight climb or descent will register on the Vertical Speed Indicator. The pilot should then adjust power so that the rate of climb indicates zero. This is the power setting required to maintain trim airspeed. Control pressures are then trimmed to zero. As a practical matter for most surveys, either airspeed or altitude will be the most critical parameter, thereby enabling the pilot to concentrate largely on holding one parameter constant while allowing the other to fluctuate slightly as necessary.

Low-level surveys sometimes require flying in a tight grid. Although the line spacing of these grids is usually determined by mission needs and therefore by preflight plans, these plans should take into account the problems involved when lines spaced too closely are coupled with relatively hig airspeeds: this combination may mean dangerous maneuvering, with high-bank angles between the exit point of one flight line and the starting point of the next line. However, certain calculations can help a pilot adjust or plan the line spacing. For instance, because the turn radius is a function of both airspeed and bank angle,

$$r = \frac{V^2}{11.26 \tan \phi}, \tag{1}$$

where r is the turn radius, V is true airspeed, and ϕ is bank angle (Hurt, 1965). At low levels, bank angles should not exceed that needed for a standard rate (3^{o}/sec) turn or 30^{o}; when line spacing is less than twice the turn radius at 30^{o} bank, excessive maneuvering can be avoided by flying a modified $45^{o}/225^{o}$ procedure turn (fig. 4A). The time that is required to fly the outbound leg can be estimated from the relation,

$$t = 40 - \left(\frac{S}{1.689V}\right), \tag{2}$$

where t is the time in seconds, S is the line spacing in feet, V is the airspeed in knots, and 1.689 is a factor for converting knots to ft/sec. This estimate will hold for a no-wind condition, but trial and error adjustments will be necessary depending upon wind conditions. An overlapping race track pattern may also be useful.

When line spacing exceeds twice the turn radius at survey airspeed and 30^{o} bank, eq. (1) can be rearranged to estimate the appropriate bank angle to allow the pilot to turn directly to the adjacent line (fig. 4B). There is some airspeed loss during turns; by increasing altitude by about 200 feet (61 m) with elevator control during the first half of the turn and descending to survey altitude to gain airspeed during the roll out, the pilot can start the flight line at trim speed. On line, bank angles for minor course corrections should not exceed 5^{o}. This will avoid extraneous accelerations and changing the orientation of the sensors.

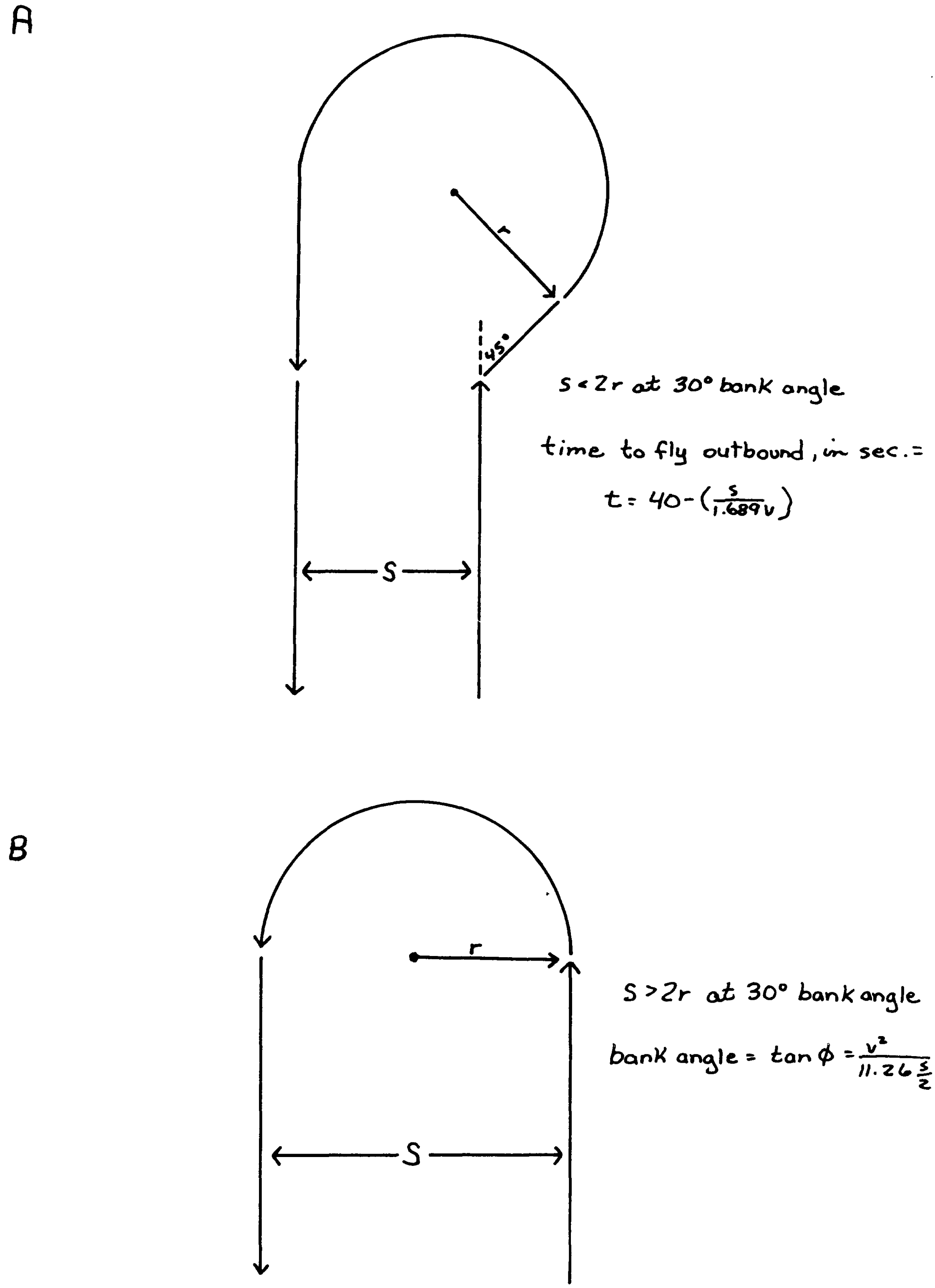

Figure 4.--Suggested end-of-line maneuvering patterns. A, when line spacing is less than twice the turn radius at 30° bank angle, a modified 45°/225° procedure turn is flown, timing the outbound leg as shown (no-wind condition). B, when line spacing exceeds twice the turn radius at 30° bank angle for a given airspeed, a lesser bank angle can be estimated that will allow a direct turn to the next flight line.

DANGERS OF LOW-LEVEL SURVEYING

Geophysical surveying is uniquely dangerous when the pilot must fly close to the ground and at low airspeeds. Although the dangers are inherent and obvious, this section provides a reminder of the the six most common dangers in these low-level surveys: (1) crashing into the ground, (2) hitting obstacles either not charted or not seen, (3) colliding with low-flying military aircraft, (4) hitting birds, (5) engine failure, and (6) being shot at by irate people on the ground. Brief comments about each of these concerns follows:

Ground contact.--Because pilots of the geophysical surveys spend much of their time flying fairly close to the ground, where reaction time is very restricted, inadvertent contact with the ground is a very real possibility. Ground crashes generally result from the classic stall/spin syndrome, arising from poor airspeed/bank control. Pilots need to be particularly conscientious, especially when the mission profile calls for low speeds, since some surveys require airspeeds as low as 52 knots (95 km/hr) (Darnley, 1972; p. 527). Turbulence and wind shear are persistent threats.

Another possibility is hitting the ground at high speeds while the pilot's attention is diverted, perhaps with cockpit chores. For example, when flying at 150 knots (275 km/hr), a 1^{o} pitch angle yields a descent rate of 250 ft/min (76 m/min); from 100 ft (30.5 m), this results in contact in 24 sec; a 2^{o} pitch has the same effect in 12 sec. Because the number of distractions on these flights means that such small pitch angles can easily go undetected (with obvious serious consequences), good crew coordination and discipline are imperative.

Obstacles.--Uncharted and unseen obstacles are a constant hazard. Constant vigilance is the watchword. A pre-survey reconnaissance flight to check for obstacles may well be worth the time and effort.

Low-flying Military Aircraft.--previously discussed, designated MTR's and MOA's are depicted on charts, but chance encounters anywhere with high speed (250 knots or 458 km/hr) low-flying military aircraft of all types from heavy multiengine bombers to jet fighters is not an uncommon occurrence (National Aeronautics and Space Administration, 1982). Again, vigilance is the watchword. Turning on landing and strobe lights during surveys will increase the survey aircraft's visibility (but may provide electrical interference and mar the results from the equipment).

Birds.--Low-level flight increases the probability of a bird strike. Since 1966, bird strikes have been responsible for $100 million in damage to military aircraft, and at least 10 U.S. Air Force crew members have been killed in these kinds of accidents; in 1982, 2,322 Air Force and Navy aircraft were involved in bird strikes resulting in $15 million in damage costs (Gregory, 1983). Flight crews are advised to fly with landing lights on, and with protective headgear with visors down.

Engine Failure.--Loss of power during low-level geophysical surveying flights is dangerous. Losing one engine on a general aviation twin-engine aircraft results in a 80-90 percent performance loss (Aarons, 1978), often making the aircraft unable to sustain flight. Specific make and model aircraft have single-engine emergency procedures specified in the Pilot's Operating Handbook. The immediate action items should be thoroughly memorized, rehearsed, and adhered to by the flight crew. Obviously, if engine failure occurs on a single-engine aircraft, the pilot's options are reduced: maintain control and land or establish an attitude for a controlled crash with minimal maneuvering.

Loss-of-power emergencies raise questions about the desireability of having a quick-release capability for the added geophysical equipment. In theory, such releases seem desireable, but in practice, they may be impractical and downright dangerous--since the separated equipment is usually aerodynamically unstable (Dixon and others, 1972), and when released, the equipment may cause the aircraft's center of gravity to shift suddenly. Also, yaw or sideslip and asymmetrical power during an engine-out emergency, may result in unsatisfactory separation because of the asymmetric aircraft configuration. Yaw, roll, and pitch moments induced during such separations, together with associated angular accelerations, may aggravate an already untenable emergency situation.

Hostile citizens.--Aircraft flying low over remote areas have been shot at presumably by illegal marijuana growers or people opposed to aerial application of pesticides or herbicides (Department of Interior, 1981). There is no certainty that those involved in this type of action can or would distinguish among aerial applicators, law enforcers, or other low-flying aircraft. Therefore, aircrews should be alert to this possibility, as well as the possibility of sabotage.

SUMMARY

Low-level surveys with fixed-wing aircraft can be conducted with acceptable risk if all involved are intimately aware of the risks. Mission requirements define the flight parameters, and a thorough understanding of the aircraft's and aircrew's capabilities will preclude making unwarranted demands on either. Flight safety can be significantly improved by careful planning. Key hazards during flight are the ground, uncharted or unseen obstacles, low-level military aircraft, birds, engine failure, and hostile citizens.

Further, protective headgear and fire-retardant clothing (Nomex or Aromatic Polyamide) are recommended for all low-level flights, and practical and realistic crew duty-time limitations should be established and adhered to.

At some stage, crew training may need to be introduced. Flight crews should receive thorough training that emphasizes the handling and performance differences between the modified and unmodified aircraft. Crews should be given adequate time to develop proficiency. For example, high sensitivity aeromagnetic surveys require that, for maximum sensitivity, the pilot fly the aircraft within an elliptical tube with a vertical dimension of 20 ft (6.1 m) and a horizontal dimension of 100 ft (30.5 m) (Jensen, 1965). This is a demanding flight envelope. Because the equipment needed for geophysical surveying has become so sophisticated, the limits of the surveying are more often defined by the flight crews' abilities than by the electronics. Therefore, the need for teamwork and training is vital for both scientific and safety reasons.

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