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HELICOPTER STORE SEPARATION - PREDICTIVE TECHNIQUES AND FLIGHT TESTING

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1.0 INTRODUCTION

1.1 Recently the NATO AGARD Flight Mechanics Panel established Working Group 15 to study the issue of integration of externally carried stores with military helicopters. A store is defined as a device intended for external or internal carriage and mounted on aircraft suspension and release equipment, whether or not the item is intended to be separated in flight from the aircraft. Stores include fuel tanks, photographic and survival equipments, and weapons.

The aim of the AGARD Working Group 15 was to determine the analysis and test methods used within NATO nations to expedite the certification of a wide variety of helicopter stores and equipment currently demanded in response to evolving military needs. The activities of Working Group 15 involved determination of helicopter store certification requirements in the aerodynamics, flight and structural mechanics and special effects such as blast, thermal and exhaust effects.

This paper summarizes the author's contribution to Working Group 15 on helicopter store separation - predictive techniques and flight testing. This paper does not go deeply into technical details but provides an overview of analyses and test methods currently used to certify the safe separation of a store from a helicopter. This paper was prepared using information gathered from NATO helicopter manufacturers and government research/test agencies.

2.0 GENERAL

2.1 HELICOPTER/STORE AERODYNAMICS

The use of a rotary-wing aircraft as a platform for carriage and relase of stores created complicated problems due to the transient environment which surrounds the launch platform. This environment is caused by the magnitude of the rotor induced flowfield velocity which fluctuates in time and space.

The perturbated flowfield induced by the rotor wake, fuselage, suspension system and adjacent stores can have a significant effect on the store separation trajectory. Some operational concpts in air launched stores emphasize that helicopters must operate at nap-of-the-earth conditions and take advantage of terrain features during store release. The rotor induced flowfield effects during store release are significant at these conditions and are maximized during hover deployment of certain stores. Thus, the store is vulnerable to rotor upsetting disturbances during the initial segment of its separation trajectory.

During release or jettison, the store should not collide with the helicopter or with any other stores and must not interfere with helicopter operations. Helicopter skids represent a potential obstacle to unpowered stores released from the helicopter side. The position of stores relative to rotor wake can have a strong effect on the separation trajectory of the store therefore creating a potential for collision. In addition, critical safe separation situations are often encountered in steep descent or in autorotation when the fuselage angle of attack reaches the highest values.

The behaviour of low weight unstable stores after jettison, such as empty launchers, canisters or fuel tanks, is strongly dependent upon the perturbated flowfield, Reference 1. Those stores whose aerodynamic loads are large in comparison to their weight and moments of inertia, are unstable when jettisoned. Being unstable, even a small aerodynamic disturbance will cause large deviation in the separation trajectory. Also being light in weight, the store may be moved with small disturbances. This results usually in large angular and displacement departures during separation. Because large angular displacements could result in tumbling, many store prediction methods will not accurately simulate the separation trajectory of unstable stores.

Figure 1 depicts a typical helicopter speed envelope (horizontal speed versus vertical speed for power on and power off conditions) showing safe and critical areas for release or jettison of stores. An envelope similar to this exists for every helicopter. The boundary between safe and critical areas depends upon the store mass properties, ejection forces and aerodynamic loading acting upon the store.

A qualitative description of the rotor perturbated flowfield is given in order to get a very general understanding of the helicopter/store aerodynamic environment.

2.2 HELICOPTER FLOWFIELD ENVIRONMENT

In hover, the rotor wake is divided into two parts: strong rolled up tip vortices; and inboard vortex sheets. The vortex sheets contract and move down rapidly below the rotor plane. The tip vortices contract, roll up and move down less rapidly than the vortex sheets, Figure 2. However, because of the interaction between vortices, flow fluctuations, fuselage effects and various manoeuvres, the geometry of the wake may vary with time. As soon as the helicopter gains forward speed, the vortex sheets and tip vortices are skewed back and they mix together.

In hover and very slow forward flight conditions, the greatest component of the rotor induced velocity is the downward component while the lateral and longitudinal components are relatively small, References 2, 3 and 4. As a result, under these conditions, the angle of attack of a side mounted store at its carriage position may reach 90 degrees with a large sideslip angle. It has also been observed, Reference 4, that the ground effect at a height of one rotor radius may reduce the total and vertical velocities by as much as 50 percent of the out of ground effect values.

The position of the intersection of a store trajectory with the rotor wake boundary is most significant as it determines the length of time a store remains in the higher induced velocity region inside the wake. It also determines the location where the close proximity of the wake boundary results in a high induced velocity on the store, thus producing supplementary loads and moments. In hover and low speed forward flight, the rotor induced velocities are the highest and large impulsive type, induced velocity variations with time will occur at points on the store trajectory near the wake boundary. These variations are caused by the passage of the rotor tip vortices. These variations decrease rapidly at points away from the rotor wake boundary and are negligible at high speed. The frequency of the flow fluctuation in the wake is the rotational frequency times the number of blades. This is considered high enough that stores which are immersed in the rotor wake will not respond to these rotor blades passage flow fluctuations, Reference 5.

Also, in hover and low speed flight conditions, as a store moves from within the rotor wake toward the wake boundary position, the downward velocity increases. As a store moves outside the rotor wake, the magnitude of the downward velocity decreases abruptly and becomes rapidly insignificant, Figure 3. This causes large flowfield incidence changes on the store during the separation trajectory and can significantly modify the trajectory of stores.

In forward flight conditions, the rotor wake boundary is skewed back, and for a single rotor light helicopter at a forward speed greater than about 30 knots, the forward wake boundary passes behind the position where fuselage side mounted stores are usually launched, Figures 4 and 5. The result is that rotor effects in that area are small compared to those of the free stream velocity. Thus, the rotor induced effects on a store trajectory decrease with increasing flight speed. The rotor wake boundary skew angle is a function of flight conditions, mainly flight speed, and rotor disk loading.

2.3 STORE SEPARATION - PREDICTIVE TECHNIQUES

In supporting the installation of a store system on a helicopter, aerodynamic analyses are made to determine aerodynamic coefficients of the store system and to predict the store separation trajectory.

Methods to predict store aerodynamic coefficients and store separation trajectories may be categorized into three broad groups: theoretical, analogy and empirical. These three groups are distinguished by their different aerodynamic approaches and each offers advantages and disadvantages.

Store separation theoretical predictions utilize fluid equations which can be coupled or uncoupled to solve the equations of motion. By coupling the fluid equations to the equations of motion, one can solve for the new attitude of the store at a specified interval of time in the store trajectory and then use this new aircraft/store physical relationship to calculate a new flowfield. Using the new flowfield parameters, the aerodynamics is updated and the process is repeated for a complete store trajectory.

A store separation trajectory can also be predicted by analogy. The analogy relies on past experience with a store of similar aerodynamic shape and mass properties and using its known separation characteristics to predict the separation behaviour of a new store.

Empirical methods are based on wind tunnel techniques which range from simple qualitative flow visualization tests to detailed measurements of force and velocity fields. These methods provide more accurate data of the helicopter-store system aerodynamic environment and loads. The wind tunnel approach can be used to carry out a specified survey of points throughout the flowfield and to produce stores aerodynamic data. These data are recalled in a trajectory prediction program when the store moves to a new point and/or attitude.

3.0 ANALYTICAL METHODS

3.1 THEORETICAL PREDICTIVE METHODS

Prediction of store separation behaviour depends upon reliable prediction of the store aerodynamic coefficients. For fixed-wing aircraft, theoretical and experimental methods to predict stores air loads are discussed comprehensively in Reference 6. The calculation of store aerodynamic forces and moments due to the free stream, fuselage and rotor interference effects can be evaluated using analytical methods. As discussed in Reference 1, purely analytical predictive methods used to determine the captive loads on stores mounted on fixed-wing aircraft utilize various panel methods that solve the linear Prandtl-Glauert equation. A general three dimensional boundary value equation is then solved for the configuration of interest. Panel methods have evolved to the point where rather complex configurations can be addressed. Higher order versions of panel methods allow a linear source and quadratic doublet variation on each panel. These improvements have helped to make panel solutions less sensitive to panel spacing and density allowing more complex configurations and problems, such as helicopter/store aerodynamic environment, to be studied.

Some computational panel methods, such as the National Aerospace Laboratory (NLR) panel method, NEAR and VSAERO, References 7, 8 and 9, have been used extensively for the calculation of the aerodynamic characteristics of complete fixed-wing aircraft configurations. The NLR panel method has been used for the prediction of aircraft-store interference effects data of the Northrop F-5 aircraft. These data have been used relatively successfully in the prediction of store aerodynamic loads and trajectories.

Such panel methods can be adapted for helicopter/store interference calculations provided that the rotor induced flowfield about the released store can be represented accurately. The VSAERO panel method, Reference 9, has been adapted to the helicopter aerodynamic environment and permits a full description of the highly interactive helicopter flowfield, including the mutual interference effects of the rotor, fuselage and stores, Figure 6. This method calculates the store loads and predicts the store trajectory.

Recently, the Royal Aircraft Establishment store trajectory prediction program for fixed-wing aircraft, RAENEAR, has been modified to predict trajectories of stores released from a helicopter at low forward speed, less than 30 knots, References 8 and 10. The main modifications to RAENEAR are the modelling of the rotor wake induced flowfield and an adaptation of the force calculation method on the store body and lifting surfaces at high angle of attacks. RAENEAR calculates the flowfield then the store loads and uses the equations of motion to calculate the trajectory.

In the modified RAENEAR, the rotor wake pertubated flowfield around a helicopter is calculated from the vortex induced velocities of a prescribed wake geometry developed from a series of wind tunnel tests, Reference 11. In the wake, the rotor blades are modelled by bound vortex lines divided into a number of segments each having a different circulation strength corresponding to the variation of the radial load distribution. Trailing vortices originate at the ends of blade segments and take a prescribed contracting helical path below the rotor. The rotor wake is set up using a prescribed wake geometry which has two parts, an inboard vortex sheet, and a strong, rolled tip vortex, Figure 2. The vortex sheet moves down rapidly below the rotor and its vertical displacement varies linearly with the blade radius. The tip vortex rolls up and moves down less rapidly than the vortex sheet. The tip and vortex sheet radial and vertical displacements are found for a given blade azimuth position as a function of thrust coefficient, rotor solidity, number of blades and blade linear twist. The modified RAENEAR was validated using wind tunnel flowfield data for the Huey Cobra helicopter, References 2 and 3, and was found to be sufficiently accurate for preliminary prediction of store loads and separation analysis.

Some separation trajectories have been simulated using the modified RAENEAR for Sea Skua missile and a rocket launcher. The stores were simulated gravity released from the fuselage side launch position of a Westland Lynx helicopter at forward speed less than 30 knots. It was found that for a store having a high mass (320 lbs) and high pitch and yaw moments of inertia (44 slug-ft2), the rotor wake has negligible effects on the store. For a low mass store, such as an empty rocket launcher, only the angular displacement in pitch is significantly affected by the rotor wake. In all cases, the lateral and longitudinal displacements and angular displacements in yaw and roll were small. It was also found that the angular displacement in pitch is a function of the helicopter forward speed and the store position relative to the rotor wake forward boundary position. At low forward speeds, the Sea Skua separation trajectories predicted by the modified RAENEAR gave a good correlation of drop flight trials. At speeds greater than 30 knots the rotor wake is not modelled, as the rotor wake effects on a helicopter launched store are assumed to be small, and the modified RAENEAR program operates as for a fixed-wing aircraft case.

Another type of store trajectory prediction method is to use the aerodynamic coefficients of the store, when they are known, as inputs to a computer store separation trajectory program. Unfortunately, the use of this method is strongly limited by the following considerations:

a. the freestream aerodynamic coefficients given by the store manufacturer, when available, are often limited to a small incidence range. This is not sufficient to predict a store trajectory where large incidences can occur just after release in the hover or at low speed cases. Also, modern anti-tank and air-to-air missiles are located in jettisonable containers for which the aerodynamic coefficients are usually unknown. Thus, wind tunnel testing must be conducted to obtain aerodynamic coefficients over a wide incidence range; and

b. it is difficult to accurately model the interference effects between the airframe and the weapon suspension system.

The confidence level in theoretical predictive methods, such as VSAERO and modified RAENEAR, for speeds between 0 to 30 knots is expected to be fair. At higher speeds, more confidence exists in the theoretical methods based upon their successful use by the fixed-wing aircraft community. However they have yet to be applied extensively by the rotary-wing aircraft community. While the analytical predictive methods are valuable design tools, the ultimate proof of a predicted safe separation trajectory for a store is found through wind tunnel and flight tests which are conducted to validate critical conditions.

3.2 ANALOGY PREDICTIVE METHODS

The second approach to predict separation trajectory of a store is to proceed by analogy when similarly shaped stores have been previously tested. As discussed at Reference 1, this approach is advantageous when a preponderance of data shows that from similarity the new store can be tested in a low risk manner. In these instances, many store characteristics are compared between the two stores - the new store and the store that has already been tested. The store analogy is established on the basis of mass, moments of inertia, centre of gravity position and physical similarity between the two stores including the platform areas.

Freestream aerodynamic data are generally compared between the stores and if experimental data are not available, semi-empirical aerodynamic estimation codes are used to generate a comparison. A simple technique to estimate freestream aerodynamic characteristics of a store is to use standard publications such as the Engineering Science Data Unit Items, Reference 12, or "Fluid Dynamic Drag" and "Fluid Dynamic Lift", References 13 and 14. These standard publications are based on wind tunnel test results for different shapes, Mach number and incidences. However, it must be noted that these standard publications are limited to stores immersed in a uniform flowfield and for given Mach number, shapes and incidence ranges.

A number of semi-empirical aerodynamic estimation codes, based on wind tunnel tests for similar shapes, may be used in conjunction with freestream data bases. These codes provide a first order estimate when freestream data are not available. These codes are also used to produce freestream aerodynamics to be used with wind tunnel techniques, such as flow angularity and grid data, as inputs to six degree of freedom trajectory programs. Most semi-empirical codes compute the aerodynamic coefficients for the geometry, Mach number/angle of attack range of interest for first order estimates of store captive loads and release behaviour.

In attempting to establish the flowfield analogy, the missing data are generally the interference flowfield effects and one should consider differences in where the stores are positioned in the flowfield. The accuracy of the analogy method is somewhat limited by the difficulty inherent to the estimation of the interference effects between the basic aircraft components (fuselage, rotor and stub wings) and the weapon installation and also, between the various components of the weapon installation itself.

For a helicopter, the perturbated flowfield is strongly dependent on the helicopter weight, height above ground, forward and sideslip speeds and aircraft manoeuvres. One should ensure that these parameters are similar for a given helicopter when establishing an analogy. The authors of this paper believe that comparison of stores attached to different helicopters should be approached with caution due to the potential differences in the helicopters weight and fuselage characteristics, rotor aerofoils, blade twists, diameters and rotational speeds. The location of each store lifting surfaces at various locations in the flowfield should be noted as well as the similarity in the suspension and release system. A primary consideration is any variation of the centre of gravity relative to the ejection force.

The basic advantage the analogy method offers is a minimal cost program for generating a flight clearance by circumventing the cost and lead time required for wind tunnel testing and/or theoretical analyses. The technique is best suited to minor design changes for previously cleared stores, or for stores of similar shapes. The greatest disadvantage is in the relative risk and the amount of judgment and experience that must be relied upon in deciding upon the approach for a particular problem.

4.0 WIND TUNNEL TESTING

4.1 EMPIRICAL PREDICTIVE METHODS

The third approach to determine the store aerodynamic coefficients and predict separation characteristics is to conduct wind tunnel tests. Wind tunnel tests are conducted on a complete scaled helicopter model or part of it.

Generally, the helicopter models do not have the main and tail rotors modelled, and therefore the wind tunnel methods are limited only to produce accurate data for moderate to high speed forward flight. Some helicopter manufacturers/laboratories have developed powered rotor systems which can be mounted on various airframe models. However, the powered model tests are expensive and time consuming and are therefore normally used only when an unexpected result occurs during analysis or appears during the flight test program. It has been demonstrated from wind tunnel tests that for a single rotor light helicopter at a forward speed greater than about 30 knots the main rotor induced flowfield does not impinge upon stores that are mounted on the fuselage sides. At high speeds, the confidence level in wind tunnel testing to determine the store aerodynamic coefficients and store trajectory is good.

The store freestream aerodynamic coefficients can also be measured in a wind tunnel. These coefficients can be used as inputs to a separation trajectory program which requires freestream aerodynamic coefficients and to validate semi-empirical estimation codes.

There are basically four wind tunnel techniques that are used to predict store separation trajectories. These techniques are: the captive trajectory system, grid, flow angularity and freedrop. A description of these techniques, as presented at Reference 1, follows. The freedrop technique is emphasized in this paper as an accurate technique to predict the trajectory of stores launched from helicopter.

To support Captive Trajectory System (CTS) testing, wind tunnels are equipped with articulated dual sting arrangements. One sting supports the aircraft model while the store model with an internal balance is mounted on a separate sting capable of commanded movement in all six degrees of freedom. Aerodynamic forces and moments on the store are measured by an internal strain gauge balance that may measure from five to six force and moment components. The aerodynamic data measured by the balance are fed to a computer during the test run. These forces and moments are combined with other required data such as store mass properties, ejection forces and moments of inertia which are needed to solve the equations of motion and predict the stores next position relative to the aircraft for a simulated increment of time. Then the store is positioned to the calculated new position and the cycle is repeated to obtain a complete trajectory.

The grid technique is essentially a flowfield mapping technique in that the store is positioned to preselected positions and attitudes with respect with the aircraft model. The store/balance combination then measures total aerodynamic coefficient data at each point. A matrix of coefficient data is obtained through a region of the aircraft flowfield that can be expected to encompass the subsequent trajectory path for a particular configuration. By subtracting the stores' freestream aerodynamic coefficients from the total aerodynamic coefficients, a set of interference aerodynamic coefficients can be calculated as a function of position and attitude with the aircraft flowfield. The matrix of interference coefficients becomes a data base available for subsequent trajectory calculations. Also, by using this technique, store captive forces and moments can be measured for different helicopter-weapon system configurations and flight conditions. Usually the aerodynamic coefficients for all stored configurations are measured for small helicopter incidence and sideslip ranges.

The flow angularity method is also used for determining interference flowfield aerodynamics. Aerodynamic data are obtained using a velocity probe attached to a sting in place of the store/balance combination. The velocity probe is used to measure velocity components at various locations in and around the aircraft flowfield within a volume that is expected to include the store's anticipated trajectory. From this information, the store local angles of attack are determined and freestream lift curve slope is used to generate the interference coefficients rather than measuring the interference coefficients themselves.

4.2 FREEDROP WIND TUNNEL TESTING

In the freedrop wind tunnel technique, also called dynamic drop, scaled store models are constructed to obey specified similarity laws and are released from the aircraft model in the wind tunnel. This technique appears to be the preferred wind tunnel testing method used at the time this paper was written to predict separation trajectory of unpowered stores released from helicopters.

High speed photography is made under stroboscopic light and video cameras are used to record the store trajectory. Multi-exposure photographs are taken to illustrate the variation of position and attitude in time. The film is read to extract time position data that can be used to understand the separation events and to assess the relative risk of flight testing. Figure 7 shows a separation trajectory of a store released from AS-365 Panther helicopter in an Aerospatiale wind tunnel.

Static aerodynamic forces and moments acting on the store are properly scaled when the model geometry and flowfield are matched to full scale flight conditions. The accelerations of the model will be similar if the total forces and moments, mass, centre of gravity, and moments of inertia are also properly scaled. The model is scaled to one of the three scaling laws: heavy, light and Froude. Selection of the most suitable scaling law depends on the nature of the separation problems. A detailed discussion of the scaling laws commonly used is given at Reference 1. It appears that for helicopter store separation testing the Froude scaling law is the most commonly used.

Freedrop testing generally offers the best approach where model size or shape precludes a suitable store-balance-sting combination design. Freedrop testing is particularly suitable for unstable stores where tumbling motion can be continued without the constraint of CTS sting mechanical limitations and allows studying multiple stores releases from racks in the ripple or salvo modes.

In most wind tunnels, the freestream is horizontal and perpendicular to the gravity vector. When testing descent or climb flight configurations this leads to a systematic error due to the fact that the gravity component parallel to the relative freestream cannot be simulated. In descent, which is usually the critical case, the simulated store path always tends to pass closer to the tail surfaces than it does during actual flight testing. Consequently, the systematic error is in the right direction for safety aspects.

The greatest disadvantages to freedrop testing lay in its cost when compared with theoretical methods and the rather limited use of the data for future study.

In summary, when compared with flight tests, wind tunnel tests offer a number of definite advantages, Reference 1:

a. no flight safety implications;

b. lower cost;

c. measurements can easily be made directly on the model as well as in the surrounding flowfield;

d. the model can be adapted to the test objectives:

(1) small scale models for studying general helicopter-weapon system configurations, and

(2) full scale models for measuring the aerodynamic loads on stores and weapon support installation; and

e. the effect of individual components of the suspension system and store can be isolated.

Conversely, problems arise in the following areas resulting in deviations from true flight conditions:

a. Reynolds number effects;

b. wind tunnel wall and airstream blockage effects;

c. interference due to model support structures; and

d. geometrical inaccuracies in the model itself.

From past experience in the helicopter community, the freedrop wind tunnel technique has proven to be sufficiently reliable to avoid unpredicted collisions with the tail surfaces during the actual store separation tests of unpowered stores. The confidence level in wind tunnel freedrop testing is only medium to high due to the lack of rotor induced flowfield effects and store scaling problems. However, it has been observed, from actual store drop trials that the rotor wake has no significant effects on the trajectory of a high inertia store. This could be explained by the low dynamic pressure that exists in the rotor wake.

4.3 WIND TUNNEL INSTRUMENTATION

Wind tunnel instrumentation particular to helicopter/store release simulation consists mainly of:

a. camera placed orthogonally to the released store;

b. stroboscopic light flashing at a determined time interval; and

c. event and time markers.

The authors believe that wind tunnel instrumentation has been discussed in an array of publications and for this reason the reader is directed to References 15, 16 and 17 for detailed discussion of this topic.

5.0 STORE SEPARATION - FLIGHT TESTING

5.1 GENERAL

Store separation flight tests are of great importance, since they are the ultimate step in verifying theoretical or empirical predictions of a store trajectory and can be used to expand the predicted separation envelope. Thus, the main objectives of store separation flight testing are to:

a. provide store trajectory data to verify results of pre-flight analysis, to complement the analysis where predictive methods are inexact, and to document the results of store separations;

b. obtain full scale store aerodynamic coefficients in the helicopter perturbated flowfield using a force balance store;

c. acquire basic flowfield data about the helicopter;

d. determine the effect of the rotor induced loading on the weapon system installation;

e. assess the helicopter behaviour during and immediately following the store launch/jettison; and

f. establish the safe flight envelope for launch/jettison of stores.

The actual perturbated flowfield around a helicopter-weapon installation from hover to high forward speed can only be determined during flight tests. The complex flowfield of a helicopter-weapon installation, that can not be simulated completely in a wind tunnel, is related to the presence of the engine air intake suction and exhaust and, rotor induced flowfield. Although good flowfield data can be obtained in a wind tunnel at moderate to high advance ratios, for forward speeds less than about 30 knots, the store aerodynamic coefficients and separation trajectories can only be evaluated accurately by flight trials.

The store captive aerodynamic coefficient measurements in the carriage position are measured directly using a five to six component balance for different helicopter-weapon configurations and flight conditions. These measurements are used to validate and improve predictions of theoretical prediction methods and to correlate wind tunnel test measurements. The test force and moment measurements can be used as inputs to theoretical trajectory predictive method which leads to a preliminary release envelope and flight release data.

While analytical store separation prediction methods and wind tunnel testing are used to define the initial flight envelope for a particular helicopter/store configuration, the results of the flight test program are used to validate and possibly expand the predicted flight envelope for safe release and jettison of weapons, launchers and canisters. Also, actual drop trials are done to ensure that the store trajectory is satisfactory and, if applicable, that the store attitudes are within the allowable specifications for seeker heads to track their intended target.

5.2 FLIGHT TEST MEASUREMENTS

In order to accurately compare flight test data to predictions and to confirm safe separation for all stores over the full release flight envelope, accurate and detailed flight test data must be obtained.

a. Captive Store Aerodynamic Coefficients

The store aerodynamic coefficients are measured using a five to six component force balance for various helicopter configurations and flight conditions. The parameters measured during the testing are:

Store Airload Parameters:

- normal, side and axial forces,
- pitch, yaw and roll moments, and
- attack and sideslip angles.

Helicopter Flight Condition Parameters:

- altitude,
- airspeed,
- helicopter weight,
- helicopter attitude angles and rates,
- helicopter velocities and accelerations, and
- outside air temperature

In ground effect:

- atmospheric conditions and wind direction/speed, and
- wheels/skids height above ground.

In order to measure store loads, a five to six component force and moment balance, built into a shape representing the store, and magnetic tape recorder onboard the helicopter are necessary to record the loads and flight conditions. Also, strain gauges are employed to measure stress directly or to measure axial loads or bending moments on store or suspension system.

These parameters are measured for various flight conditions such as:

- hover in ground effect,
- hover out of ground effect
- horizontal flight at different altitudes
- climb and descent,
- autorotation,
- sideslip flight, and
- manoeuvring flight

b. Store Separation Trajectory

In order to acquire sufficient data to analyse the store separation trajectory the following parameters, in addition to the helicopter flight condition parameters as presented in sub-paragraph a., should be recorded:

Store Mass Properties:

- weight,
- centre of gravity, and
- moments of inertia.

These should be determined prior to flight testing for each store released.

Store Drop Conditions:

- store carriage position,

- store attitude angles and rates (pitch, yaw and roll),

- store accelerations, and

- time of release.

Store Separation Trajectory Data:

- store attitude angles, and

- store linear and angular displacements.

5.3 FLIGHT TEST INSTRUMENTATION

The test instrumentation should be set-up so that it does not alter the aerodynamic flowfield in the proximity of the weapon system installation. The flight test instrumentation needed to acquire store separation data are as follows:

a. a central time code to time-correlate all acquired data whether on the ground or airborne;

b. 16 mm high-speed motion picture cameras for airborne photometric analyses which can be augmented by video camera systems. These cameras are mounted in or on the project aircraft fuselage and are used to:

    (1) provide time/position history information to document the separation characteristics of the stores under various release conditions,

    (2) monitor arming wires and lanyard behaviours, ejectors, release sequencing and debris, and

    (3) provide a pilot's eye view of store separation;

c. cameras mounted on, or hand held aboard, a chase helicopter can also be used to provide a global perspective of the store separation. Occasionally, hard mounted cameras experience vibration problems but these can be mitigated by the use of stablilization platforms for electro-optic sensing systems, such as the Tyler or Westcam platforms. These platforms can accomodate cine or video cameras; and

d. a magnetic tape recorder to record the helicopter flight and store release parameters.

At the heart of obtaining detailed store separation trajectory data lies the camera. Selection of the proper camera, film, frame rate, lens, aperture and camera locations are all extremely important. The reader is directed to Reference 1 where a detailed discussion on flight test instrumentation is presented.

An alternative to measure store attitudes during drop tests is to install an instrument pack within the released store. The store attitude data acquired via accelerometers during a drop is transmitted to a data recording system by telemetry or via fibreoptic cables. The use of fibreoptic cables at MBB has proven to be a very reliable method of transmitting data.

5.4 FLIGHT TEST INSTRUMENTATION TOLERANCES

Reference 1 suggests tolerances for the allowable accuracies of the flight instrumentation systems for fixed-wing aircraft. The suggested instrumentation measurement tolerances are as follows:

<u>Store Mass Properties</u>:

weight	+/- 1%
centre of gravity	+/- 0.25 inch
moments of inertia	+/- 1%

<u>Aircraft Flight Conditions at Stores Release</u>:

altitude	+/- 50 feet
airspeed	+/- 5 kcas
pitch and roll angles	+/- 2 degrees
acceleration in all axes	+/- 0.01 g
yaw angle	+/- 1 degree

<u>Store Trajectory Data</u>:

angular measurements	+/- 2 degrees
linear measurements	+/- 1 inch
time	+/- 0.01 second

The authors of Reference 1 believe that these tolerances are adequate for trajectory analysis. However, it is believed that the altitude and airspeed tolerances should be +/- 5 feet and +/- 2 kcas respectively for rotary-wing aircraft. A more stringent accuracy may necessitate a costly and sophisticated instrumentation and data reduction system that is just not needed.

6.0 ASSESSMENT OF THE STATE-OF-THE-ART

The techniques used to predict stores airloads and to certify stores for safe separation from fixed-wing aircraft can be followed and adapted for rotary-wing aircraft.

The analytic prediction methods presently in use in the fixed-wing community are limited to Mach number above 0.3. However, since some analytic methods have proven to predict separation trajectories for stores released from a fixed-wing aircraft to a high confidence level, they should be adapted as the basis for helicopters.

The authors believe that the best approach to helicopter/weapon integration is to conduct a program which is balanced in terms of use of analytical methods, wind tunnel and flight tests to evaluate all aspects of a particular helicopter/weapon integration problem. The adaptation of computational panel methods to the helicopter aerodynamic environment, such as VSAERO, NLR and RAENEAR, to estimate the store captive loads and store separation trajectories could reduce significantly the wind tunnel and flight testing requirements for the certification of a weapon system on a helicopter. In parallel to the development of store captive loads and separation trajectory prediction methods, wind tunnel and flight tests should be conducted to provide validation data for the analysis. No matter what the state-of-the-art becomes in store aerodynamics and separation prediction techniques, flight testing should not be eliminated.

The techniques used in North America and Europe to predict the separation trajectory of stores released from a helicopter are presently evolving at a rapid rate. Present technologies are, in a technical sense, still immature, and potential improvements are envisioned within the next decade as the warfighting capabilities of the helicopter are fully exploited.

7.0 FIGURES

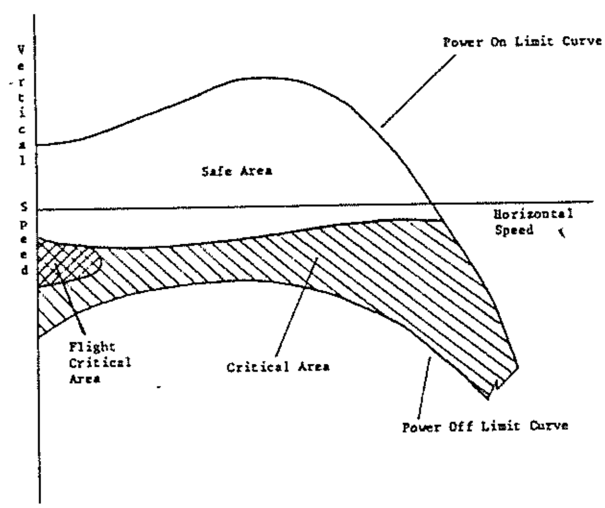

Fig 1: Typical Helicopter Horizontal Speed Versus Vertical Speed Store Separation Flight Envelope (Power On/Off)

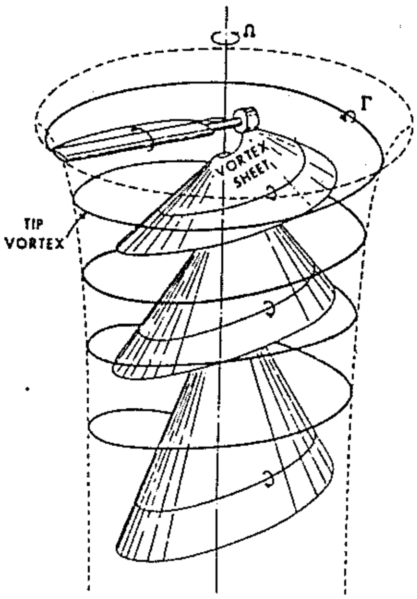

Fig 2: Rotor Hover Prescribed Wake (ref 11)

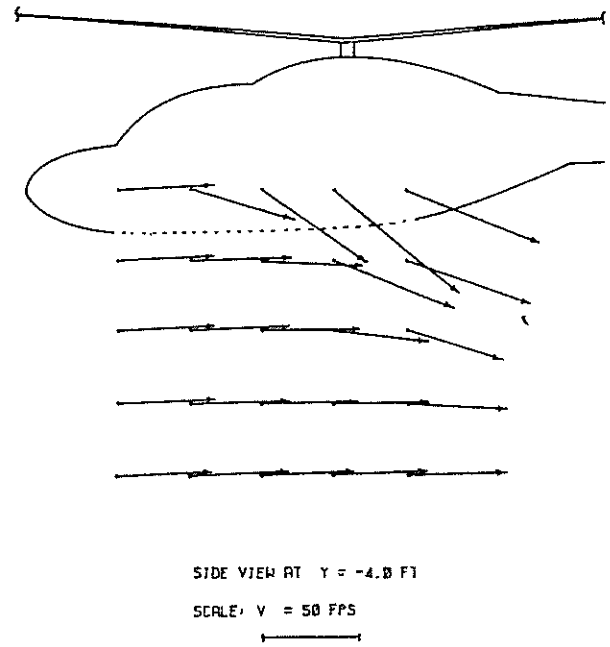

Fig 3: Modified RAENEAR Lynx Helicopter Calculated Flowfield $C_T = 0.0061$ $V_\infty = 30$ knots (ref 10)

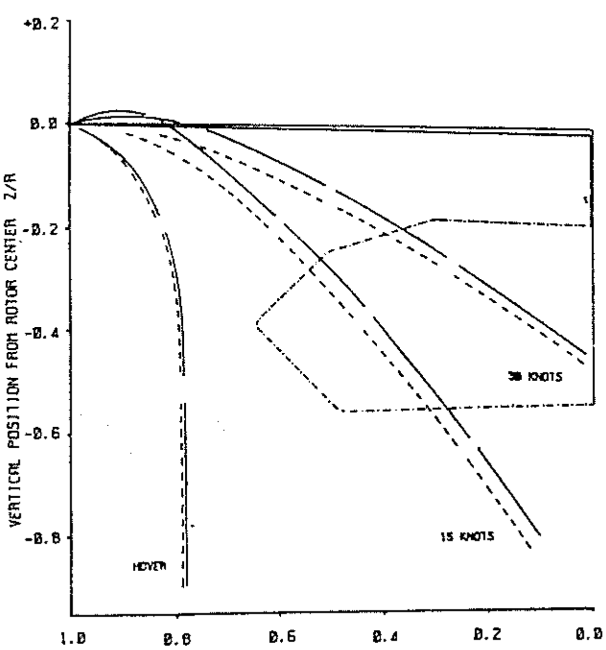

Fig 4: Front Rotor Wake Boundary Position Variation with Forward Flight - AH-1G Helicopter

$C_T = 0.00472$

---- Wind Tunnel (Refs 2,3)

\- - Predicted (ref 10)

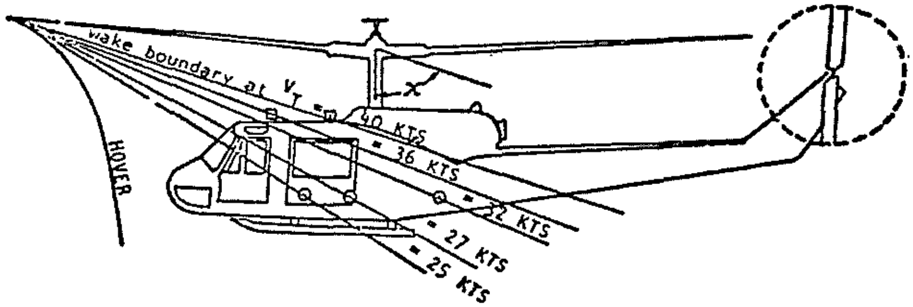

Fig 5: Rotor Wake Bouandaries In Forward Flight
UH-1M Helicopter (Ref 5)

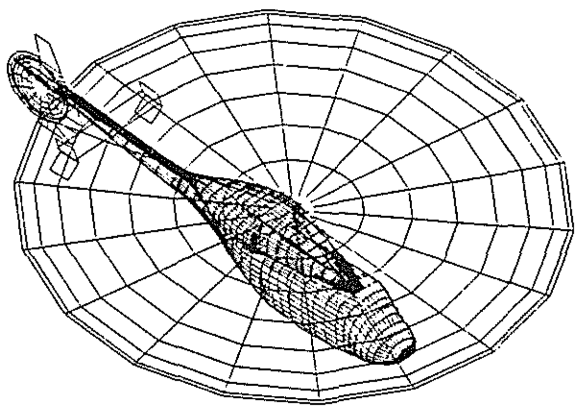

Fig 6: Basic Body Model with Nacelles and Tail Surfaces (Ref 9)

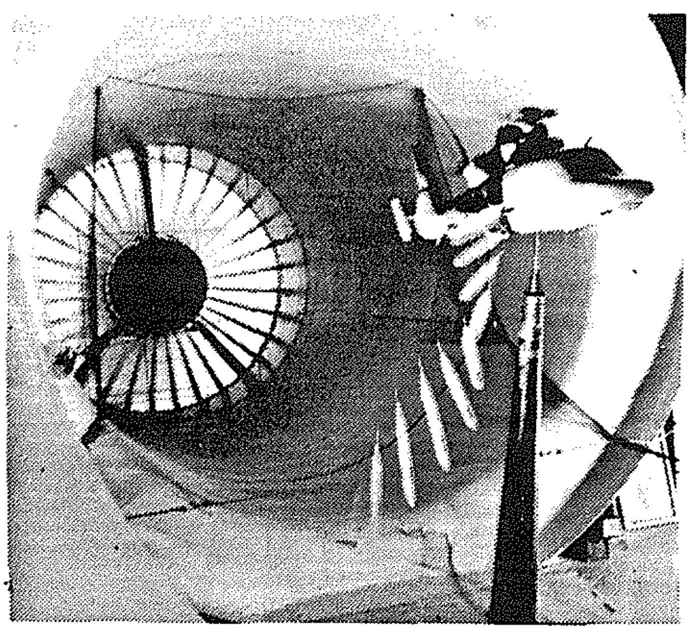

Fig 7: 20 mm Gun Pod Released from an Aerospatiale AS 365 - Panther

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