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AN APPRECIATION OF THE DYNAMIC PROBLEMS ASSOCIATED WITH THE EXTERNAL TRANSPORTATION OF LOADS FROM A HELICOPTER - STATE OF THE ART

by

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SUMMARY

Recent experience has shown one of the major attributes of a helicopter is its capacity to transport external loads. It is usual that the complete speed range of a helicopter cannot be utilised because of the dynamic instabilities of the external load/sling arrangement. The paper emphasises the difficulties of stabilising loads at high forward speeds on the conventional single point suspension. The discussion is extended to techniques that are now being investigated to achieve dynamic stability for a broad spectrum of helicopter underslung loads when they are transported at forward speeds of up to 150 knots.

1. INTRODUCTION

Over the past few years the helicopter has proved to be a highly effective and versatile means of transporting loads, particularly when slung externally from the fuselage. The most significant advantage of using helicopters in this role is that of aerial access, especially in terrain that is difficult for ground vehicles. Furthermore, transportation times are significantly shorter than for ground vehicles provided the speed capability of the helicopter can be fully utilised.

Helicopters now have the capability of attaining forward speeds in the order of 150 knots. However, when transporting loads externally, the maximum forward speed is usually severely reduced due to, among other factors, the power and control limitations imposed by the load on the helicopter. More generally, however, the most important cause of speed reduction is the onset of dynamic instability of the load. As a consequence during the last few years there has been a vast increase into the stability investigations of helicopters when carrying underslung loads. It is the intention of this paper to examine the present state of the art on these investigations and discuss in some detail

(a) the present difficulties encountered when transporting a load on a conventional single point suspension from a helicopter

(b) factors which contribute to load instabilities

(c) the techniques that are now being employed for a broad spectrum of loads to achieve helicopter/load stability at forward speeds in the order of 150 knots

(d) the correlation that exists between theory, wind tunnel and full scale results.

It is interesting to note, however, that in 1915 Bairstow, Relf and James (1) were concerning themselves with the dynamic stability of captive balloons. Since then Glauert (2) and Brown, Bryant and Sweeting (3) have pursued theoretical approaches on the more general use of a body towed by a single wire. In 1963 Etkin and Mackworth (4) carried out an analytical investigation on the stability of a towed bomb-shaped bucket. It was not until the early 1960's, however, that experimental investigations (both model and full scale form) were executed to determine the dynamic stability of towed bodies. For example, Shanks (5-7), showed experimentally that dynamic instabilities can occur when towing half-cone re-entry vehicles and parawing gliders through the air. Furthermore, Austin (8-10) and Sheldon (11) performed wind tunnel experiments on helicopter underslung palletised and container loads to ascertain the stability limitations on the helicopter forward speeds. Lancashire et al(12) and Hodder (13) of Boeing Vertol were pursuing similar investigations on a broad spectrum of predominantly military loads. Some of the knowledge gained from the above investigations has contributed to certain improvements on the general 'day to day' carriage of loads (on a conventional single point suspension) from a helicopter. However, there are frequent instances where, due to the lack of knowledge by the operators, external loads are being jettisoned by helicopters because of load instabilities.

2. Present State of the Art

Within the Western World, the vast majority of loads that are carried externally from a helicopter are suspended from a single point arrangement. In other words, the load is suspended from a single hook which normally can be winched from the helicopter (see fig 1). Except for the significant research work on two point suspension arrangements, (which will be discussed in depth later) the Sikorsky CH 54A Skycrane and the Russian MIL 10 suitably transport external loads by rigidly constraining the loads to the helicopters. This approach, unlike the cable suspension approach, would appear to impose no serious limitations on the dynamic behaviour of the two heavy lift helicopters. Therefore, it is worthwhile considering how helicopter operators at the present time, are "living with" the dynamic limitations of carrying external loads from a helicopter on a single point suspension.

Fig. 1

Fig. 2

3. Limitations of the Single Point Suspension

Commercial and military operators accept the fact that using a helicopter for external load transportation tasks is usually expensive in terms of both money and time. Such are the tasks, however, that only a helicopter can complete the operation successfully, ie inaccessible sites.

Due to the lack of expertise on carrying external loads, most helicopter/external load operations are limited to forward speeds below 60 knots. It is only the occasional load that can be externally transported (on a single point suspension) in a stable manner above 60 knots. This is because most 'difficult' loads become dynamically unstable or, alternatively, the aerodynamic drag becomes excessive, resulting in power or control limitations on the helicopter. Not surprisingly, the types of load carried by helicopters fall into three categories and a distinct relationship exists between aerodynamic instability characteristics and load density and shape. The three groups are as follows

(a) High density axisymmetric loads

(b) High or medium density elongated loads

(c) High drag low density loads.

(a) The high density axisymmetric load is well illustrated by the netted load (ie jerry cans) or a heavily laden cube like box load. This produces a load which has near axial symmetry which might spin above its vertical axis on a swivel, but can remain stable up to high forward speeds ie above 100 knots, (ref 16). These type of loads usually have poor aerodynamic drag characteristics, however, and a small helicopter would be power or control limited below a forward speed of 100 knots and the load can be carried at only intermediate speeds.

(b) High or medium density (elongated) loads are typified by missiles, guns, trucks, armoured vehicles, telegraph poles which generally have a distinct major axis. When mounted on a single point suspension, certain of the above loads maintain their major axes 'in line' with flight and are appreciably more successful in attaining high forward speeds than loads that naturally adopt a partial 'broadside on' position to the direction of flight. Both wind tunnel and full scale experience of the latter loads has shown unstable load behaviour at low to moderate forward speeds (see ref 14 and 15). For example, the 0.75 tonf (7.5 kN) land rover when carried at forward speeds in excess of 65 knots develops a yawing oscillation which induces a large fore-aft pendulum oscillation and the combined motion diverges into very large amplitude oscillations. On the other hand, the 0.25 (2.5 kN) and 0.5 (5.0 kN) tonf land rovers are aerodynamic stable up to 110 knots at which speed the helicopter became power limited. Clearly, there is a strong cause for judging each load on its individual dynamic stability merits.

(c) High drag low density loads almost invariably exhibit dynamic instabilities at low to moderate helicopter forward speeds. Typical loads include rectangular containers (fig 2), bridges, boats, stripped helicopter fuselages and plate-like loads. The few loads that have good 'weathercock' stability in this class are normally endowed with large drag coefficients and impose power or control limitations on the helicopter at only moderate speeds. A good example of this is given in figure 3 where the Chinook fuselage is being transported at only 70 knots. Similarly the CH-34 helicopter fuselage is a stable load up to 100 knots. On the other hand, the International standard rectangular container (unladen) (20 x 8 x 8 ft) and class 16 and medium girder bridges inevitably fly 'broadside on' to the wind thus effecting large drag forces. Even at forward speeds of 40 knots, the container develops a severe combined yaw and lateral pendulum divergent oscillation (see ref 12, 16 and 17), whereas flat plate-like loads such as class 16 bridges develop large amplitude lateral pendulum oscillations in their trailed position (see ref 18, 19 and 20). Both types of oscillation generally develop so rapidly that unless the helicopter pilot rapidly reduces forward speed, then both loads would have to be jettisoned before the helicopter became uncontrollable.

To summarise, it is useful to present a table of typical loads (and their limiting forward speeds in level flight) when mounted on a single point suspension from a helicopter (fig 4). These results are only typical because stability limits vary significantly with, for example, suspension sling height, climb and descend rates in forward flight and the load centre of gravity position.

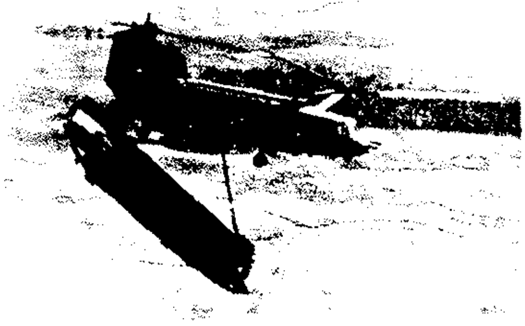


Fig. 3

Load	Instability Mode	Instability Speed (kts)	
		Full Scale	Wind Tunnel
8x8x20 ft Container	Yaw-Lat Pend Oscillation	40	30
Land Rover 7.5 kN	Yaw-Oscillation	65	65
120 mm Wombat Gun	Yaw-Lat Pend Oscillation	70	65
Trailer 3.8 kN	Lat. Pend Oscillation	60	61
Class 6 Bridge (6.3 kN)	Lat Pend Oscillation	45	
Conex Box 6.7 kN	Rotation	65	40-50

Fig 4 - Limiting Stable Speeds of Loads on a Single Point Suspension

4. Load Stabilisation Techniques

From the previous discussion it should be apparent that for helicopters (with external loads on a conventional suspension) to achieve 'realistic' forward speeds in the order, say, of 100 knots or more, then operators have resorted to various load stabilisation techniques, on the assumption that helicopter power and control limitations will not then become significant. Numerous forms of stabilisation now exist, but space does not allow a discussion on all the possibilities.

Such techniques as the aerodynamic load shaping (see ref 9), cargo swing beam, the torque tube, augmented stability control (see ref 12) and piggy back loads are considered of secondary usage to the following:-

(a) Addition of fins

(b) Drogue chutes

(a) Addition of Fins

Most loads (underslung from the conventional single point suspension) with a length/breadth ratio greater than 1.5 and their centres of gravity and volume in close proximity, will normally present themselves to the wind in a broadside or near broadside position. The load naturally adopts a maximum drag attitude.

Fins are added to certain loads with the above characteristics for two basic reasons:

i) increase the stable range of forward speeds

ii) align the minimum drag position of the load with the direction of flight

The attachment of fins to various loads has been experimented with, almost exclusively, in the United Kingdom (ref 18, 19, 20). This work was predominantly concerned with military bridging (see fig 5) although other loads have been experimented with on wind tunnel and full scale trials (ref 21, 22). With the significant reductions in the weight of modern medium girder (MGB) and air portable bridges (APB), together with the increased lifting capacity of modern helicopters, it is a feasible proposition to transport bridging by helicopter, provided adequate forward speeds could be maintained. Without the addition of fins, most bridging is limited below 50 knots forward speed, because of divergent lateral pendulum oscillations or large trail angles (large drag and negative lift forces) imposing power or control limits on the helicopter.

The addition of twin fins (of optimum size for stability) as shown in figure 5 has been shown in wind tunnel and full scale studies (ref 18, 19, 20) to produce a significant improvement in attainable helicopter speeds. Subject to the fins not being over size and producing a pitch divergence of the bridges, a very significant reduction can be achieved on helicopter hook loads and aerodynamic drag. From the results of wind tunnel tests on various bridges with optimised twin fins (ref 18, 23) of which fig 6 for a 50 ft (15.2 m) APB is typical, it was found that on average for all MGB and APB's tested at 85 knots forward speed a 80% reduction in the nett aerodynamic effects on hook load and more than 50% reduction in drag forces on the bridging was effected. This decrease in 'loading' was confirmed by the full scale trials and clearly allows the helicopter to attain much higher forward speeds, than with the unfinned bridge, without power or control limitations occurring. However there still exists a logistical problem of supplying fins to bridging.

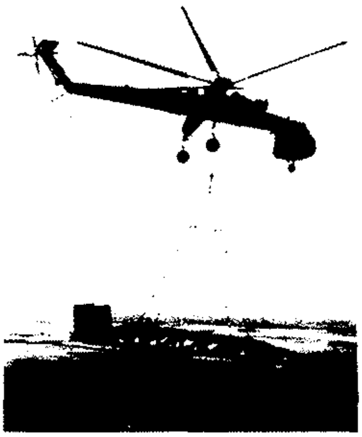


Fig 5

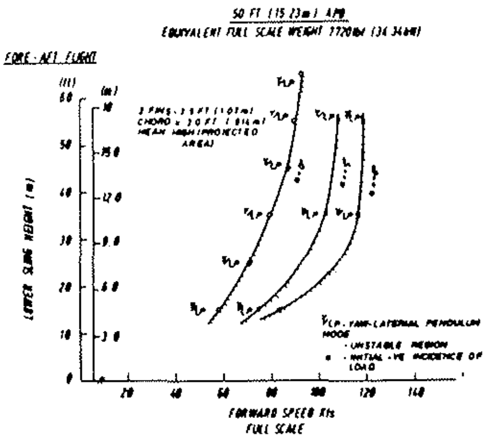


FIG 6

Whilst most of the experience with fin stabilisation has given encouraging results, only moderate interest in this technique has been shown in the USA, probably because drogue chute stabilisation is more in vogue.

(b) Drogue Chutes

The drogue chute probably achieves the same stabilising effect as the fins on most loads. Effectively a drogue chute of sufficient size, mounted on the major axis of a load, should give sufficient control of lateral and fore-aft pendulum excursions of a load. To a lesser extent yaw excursions should also be limited. Furthermore, a drogue chute can be used to position a load in its minimum drag position.

Over and above the logistical difficulties of fins, the drogue chute has a considerable drag effect, and therefore helicopter power or control limits will take on importance at lower forward speeds than if fins were adopted.

Furthermore, there is strong evidence from Vietnam experience that rigging a drogue (and similarly fins) to a load can be difficult, time consuming and dangerous in a combat situation. In forward flight the drogue chute can have a very erratic behaviour due to trailing vortex action from the load. This can soon damage the drogue to the extent it will become ineffective. It is the opinion that, except for the occasional task, some means other than drogue chutes or fins to stabilise a load would be desirable (ref 24).

5. Future Stabilisation Concepts

The discussion so far has been centred on the present techniques of stabilising a load on a single point suspension from a helicopter. It may be generally concluded that, because there is no control over the trail angle of the load, then, even with fin or chute additions, power or control limits on most helicopters have been found to keep forward speeds at less than 100 knots. With medium and heavy lift helicopters capable of forward speeds in excess of 150 knots, then it has proved necessary to develop other forms of stabilisation systems.

The major areas of research and development in the UK and USA are now concerned with the potential of multi-point suspension systems. Whilst a number of forms of multipoint suspension exist and are well documented in references 12, 24, three types would appear to have distinct advantages over other forms.

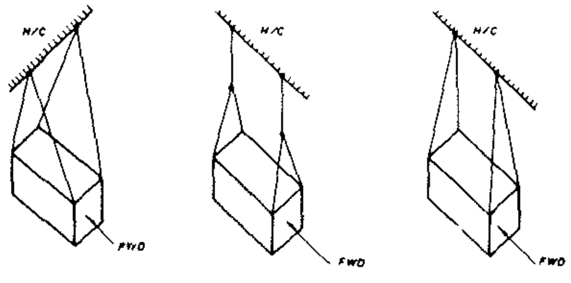
(a) 2 point tandem suspension (inverted 'Y' type) - Boeing Vertol

(b) 2 point tandem suspensions (inverted 'V' type) - MOD/RMCS/BAH

(c) 2 point lateral suspension - MOD/RMCS/WH

It is intended to cover these suspensions in some depth and compare their relative stabilising characteristics in a general manner.

Wind tunnel and full scale experience has shown that a large number of load instabilities (on single point suspension) are initiated by yaw motions of the loads. Two attachment points displaced some distance apart on the helicopter is one of the simplest methods of achieving yaw restraint on the load. These points can be displaced laterally or in tandem on the centre line of the helicopter (see fig 7). A four point suspension also achieves some yaw restraint on the load,(but to a lesser extent than the inverted 'V' suspension). Also major problems do limit its potential (see ref 24).



LATERAL   INVERTED 'Y'   INVERTED 'V'

FIG 7 TWO POINT SUSPENSION SYSTEMS

LOAD	SLING LENGTH (FT (m))	SPREAD FT(m)	SINGLE POINT		2 PT LATERAL		2 PT TANDEM 'Y'	
			U/T	T/T	U/T	T/T	U/T	T/T
EMPTY CONTAINER 8x8x20 FT (2.4x2.4x6.1m)	20(6.08) 15(4.56) 12(3.65)	0 6(1.82) 15(4.56)	30	40	150	-	150+	60 + P.L
0.5 TONE TRAILER (3.8 KN)	11(3.36) 12(3.65) 12(3.65)	0 3(0.91) 10(3.04)	62	60	130+		110	100
0.75 TONE LAND ROVER (16.5 KN)	22(6.69) 14.5(4.4) 12(3.65)	0 6(1.82) 10(3.04)	65	65	130+		150+	120+ P.L
120 mm COMBAT GUN (3.1 KN)	20(6.08) 15(4.56) 12(3.65)	0 6(1.82) 15(4.56)	65	70	130+	90+PL	150+	120+ P.L

P.L - INDICATES HELICOPTER POWER LIMITS   ALL SPEEDS IN KNOTS (FULL SCALE)

FIG 8. COMPARATIVE STABILITY DATA FOR VARIOUS LOADS

The majority of research and development on multipoint suspensions which began in 1964 has been performed independently by Boeing Vertol and a joint collaboration between MOD, Royal Military College of Science and British Airways Helicopters. A variety of loads have been investigated in both the areas of study. Initially these loads were tested in the wind tunnel for dynamic instabilities and then the work was extended to full scale trials to ascertain the handling difficulties of a helicopter with a load on a multi-point suspension.

Wind tunnel results are presented in fig 8 of the improved stability of the 2 point tandem suspension (V type) and 2 point lateral suspension compared with the single point suspension of a 120 mm light gun, 0.75 tonf truck, 0.5 tonf trailer and a 2 tonf (19.9 kN) rectangular container. Results are also presented of the full scale trials on these loads with the two point tandem (V type) suspension. Unfortunately in a number of cases the helicopter was power limited and the wind tunnel results could not be confirmed (ref 25) at the higher speeds, although good correlation is confidently expected because excellent correlation has existed on other trials (ref 26). A similar picture of very significant improvements in stability is given by the 2 point tandem (Y type) suspension developed by Boeing Vertol. (see ref 26, 27). It is quite clear from fig 8 that both tandem and lateral suspensions produce improved stability over the single point suspension. For all the full scale trials with the suspensions optimised for maximum stability pilot induced oscillations quickly damped and the overall stability of the helicopter alone was not significantly altered. The lateral suspension requires significantly less spread to impose the same yaw stiffness on the load (see fig 9) and the load centre of gravity position does not influence helicopter in-flight stability. However, it has no control over the load trail angle (see ref 29, 30). As trail angle control will influence the power and control limitations on the helicopter, the tandem inverted 'Y' and 'V' suspensions are preferred and are being adopted as the simplest, most effective multipoint suspensions for future helicopter external load transportation at high speeds.

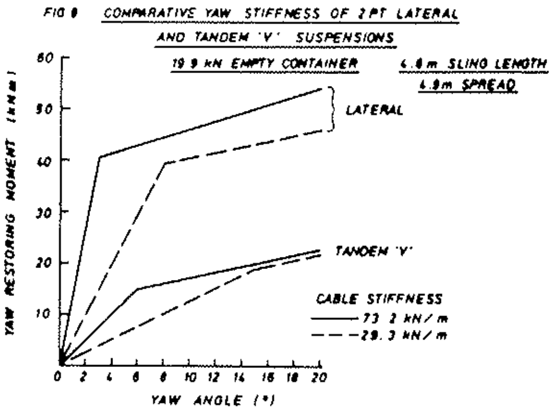


FIG 8 COMPARATIVE YAW STIFFNESS OF 2 PT LATERAL AND TANDEM 'V' SUSPENSIONS

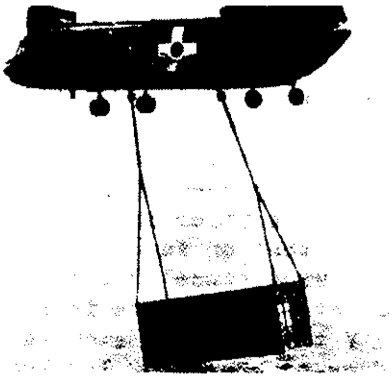


Fig.10

With the continual uprating of helicopters, the standard 2 tonf (8 x 8 x 20 ft) (2.43 x 2.43 x 6.1 m) container is considered to be the most suitable form of platform for carrying equipment externally (on a two point tandem suspension) from a helicopter. Aerodynamically it is proving to be a most difficult load to carry in the unladen condition. As great interest is being shown (on both sides of the Atlantic) in this type of load, it should be fruitful to present a brief in-depth study of the problems that have been encountered with the helicopter - container combination.

Two approaches are now being made to stabilise a standard container on a tandem suspension at forward speeds up to 150 knots. The Boeing-Vertol approach would appear to use the tandem inverted 'Y' type suspension with the empty container adopting an approximate 10° nose down attitude to the aircraft fuselage (see fig 10); the most stable attitude. With 7.5 ft (2.28 m) riser cables and a 12 ft (3.65 m) spread, the container is stable, but power limited (on the test helicopter) at 115 knots forward speed (refs 26, 27). However, there is evidence that for essentially the same suspension (with 16 ft (4.87 m) forward slings, 12 ft (3.65 m) aft slings and 8.0 ft (2.4 m) risers, the empty container has unstable tendencies in yaw at speeds above 70 knots; a result which is confirmed by wind tunnel trials and presented below. If instabilities of this kind can occur, then as part of the Boeing HLH research and development programme, an active arm external load stabilisation system (AAELSS) will be employed to damp out load excursions. This sophisticated and expensive equipment is shown basically in figure 11 but is too complicated to discuss in this paper (see ref 28).

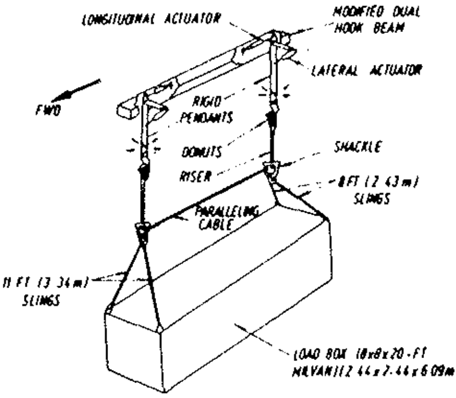


FIGURE 11 ACTIVE ARM EXTERNAL LOAD STABILISATION SYSTEM (AAELSS)

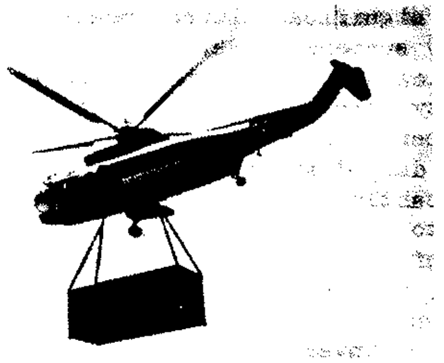


Fig. 12

The inverted V tandem suspension of a standard container developed at the RMCS in the wind tunnels and tested full scale by British Airways Helicopters under MOD contract has already been touched on briefly. Whilst wind tunnel results predict load stability up to 150 knots with a realistic size of suspension, power limits (on the test helicopter) have kept forward speeds down to 60 knots at present (fig 12). However, because the inverted V suspension is significantly stiffer in yaw than the inverted Y suspension, it is not anticipated that an augmented load stabilisation system will be required (see fig 13). Wind tunnel results on variations of sling length and suspension spread on stable forwards is presented in fig 14 for the empty container on an inverted V tandem suspension (see also ref 29, 30, 31). It is apparent that stable forward speeds of 150 knots are attainable with 15 ft (4.56 m) slings when the spread is between 10-20 ft (3.04-4.08 m). A spread of 14 to 16 ft (4.3 to 4.9 m) for the container would, however, delay the onset of helicopter power limits and optimise for the highest forward speed.

Whilst the major emphasis has been placed on load stabilisation techniques, it should be realised that other dynamical problems such as 'sling leg' flapping, 'vertical bounce' of the helicopter/load combination and inadvertent hook release problems can still exist. However, the mechanics of all three problems have been appreciated to the extent that such catastrophes can be avoided (see ref 26, 31).

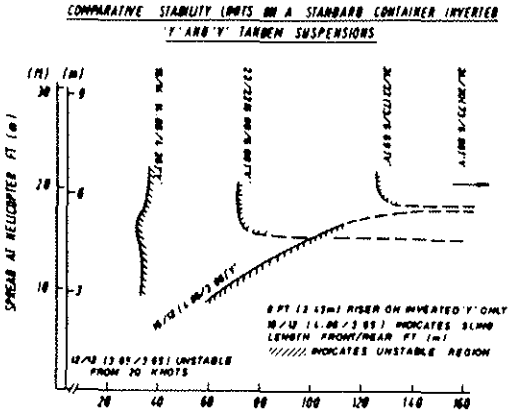


FIG 13

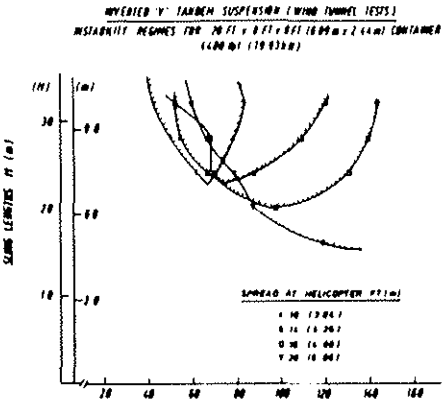


FIG 14

6. Conclusions

Extensive wind tunnel and full scale trials have indicated the serious speed limitations imposed by most loads when underslung from a helicopter on a single point suspension. Furthermore, the stability of each load must be judged on its own merits. The merits of the tandem suspension are such that the vast majority of loads can now be stabilised at forward speeds in excess of 150 knots, provided that due consideration is given to the power and control limits of the helicopter. Furthermore, external load transportation by helicopter should be independent of weather conditions.

7. Acknowledgement

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