Impact Of Helicopter Vertical Fin On Tail Rotor Performance In Hover

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Abstract

It is well known that the tail rotor wake affecting the helicopter vertical fin in hover results in a force applied to the fin but opposite in direction to the tail rotor thrust. The results of the experiments on that problem are known too, Ref. 1. However, the opposite effect, i.e. the impact of the fin located within the tail rotor wake in hover on the tail rotor performance appears not to have been studied yet.

The paper analyses the results of tests obtained on the tail rotor operating both separately and in presence of the fin. The impact of the fin on the performance of the tail rotor operating both as a tractor and a pusher is found out. It has been revealed that the fin located within the tail rotor wake exerts some positive influence on the rotor performance. This conclusion is different from a short remark made in Ref. 1 with respect to the pusher tail rotor that its efficiency loss is experienced due to blockage of the airflow in front of the rotor.

Introduction

An increase in the engine power of single rotor helicopters being upgraded is always linked with the problem of providing sufficient tail rotor pitch margins. The same problem should be considered if the temperature, altitude and airspeed envelopes have to be widened. The increased maximum airspeed makes helicopter designers solve the problem of tail rotor offloading at high airspeeds by installing a vertical fin producing a lateral force to counteract a part of the main rotor torque.

However, a vertical fin located within the tail rotor wake in hover produces a lateral force opposite to TR thrust which should be compensated by an extra TR thrust increase provided by the increased tail rotor pitch.

The last problem was quite sufficiently studied in Ref. 1, however, the opposite effect of the fin located within the tail rotor wake in hover, i.e. its impact on the tail rotor aerodynamic performance appears not to have been studied yet

The experimental research done by the TsAGI and Mil Helicopter Plant was dedicated to this problem.

Notations

A, m^2	TR disk area
c, m	Blade chord
$C_Q=2Mk / (\rho\sigma\pi R^3(\omega R)^2)$	TR torque coefficient
D, m	TR diameter
k	Number of blades
M_k, kgf*m	TR torque
M_o	Blade tip Mach number
ρ, kg $*s^2/m^4$	Air density
R, m	Radius
S_{fin}, m^2	Fin area
S_{fin}/A, %	Relative fin area located within TR wake
$ty=C_T/\sigma=2T/ (\rho\sigma\pi R^2(\omega R)^2)$	TR thrust coefficient
$\overline{V}=V/(\omega R)$	Advance ratio
Z_{fin}/R	TR-fin relative separation distance
T, kgf	TR thrust
Δφ°	Geometrical blade twist
$\Theta°_{fin}$	Fin pitch relative to the helicopter longitudinal

	axis
$\varphi°$	Blade pitch
$\sigma=kc/(\pi R)$	TR solidity
ω, s^{-1}	TR speed

Statement of the problem

While developing an upgraded version of the Mi-8MTV helicopter the installation of a vertical fin instead of the existing tail rotor pylon was considered. A larger fin installed in the helicopters flying at a maximum speed of about 300 km/h is mainly intended to offload the tail rotor at high speeds leading to its lower loading.

However, while the vertical fin produces a positive effect at high speeds it also produces a negative one in hover. As the fin - tail rotor system produces a lesser lateral force to counteract the main rotor torque than that of an isolated tail rotor at the same level of power required, the problem of an increase in the maximum tail rotor pitch as well as an increase in tail rotor power required arises.

The analysis of the results obtained from the whirl tower and full-scale test bench tests conducted for the Mi-24 has revealed a difference in the tail rotor power required vs. pitch. It was supposed that the vertical fin could be the cause of the difference as the tail rotor had been tested in presence of the vertical fin on the Mi-24 full-scale test bench meanwhile on the whirl tower it was tested separately.

It is well known that the tail rotor wake effecting the helicopter fin in hover results in a force applied to the fin and opposite to the tail rotor thrust.

The results of experimental studies of this problem are known from R. Linn's paper (Ref. 1) and some of them are shown in Fig.1.

The aim of the tests discussed in the present paper was to find the impact of the fin located within the tail rotor wake on the tail rotor performance, namely, on its polar, tail rotor thrust and power vs. blade pitch, in particular.

The MMHP whirl tower used to test the full-scale tail rotor in presence of the Mi-24 fin is shown in Fig. 2. The tests were carried out under the supervision of M.A. Greengaus.

The TsAGI carried out tests of the tail rotor and fin scale models in the T-105 wind tunnel independently of the MMHP.

The TsAGI tests were conducted in hover and in air stream whose velocity corresponded to advance ratio ranging from $\overline{V}$=0.1 to $\overline{V}$=0.4 at different yaw angles. However, to be in the framework of the subject being discussed, only the hover test results are presented in this paper.

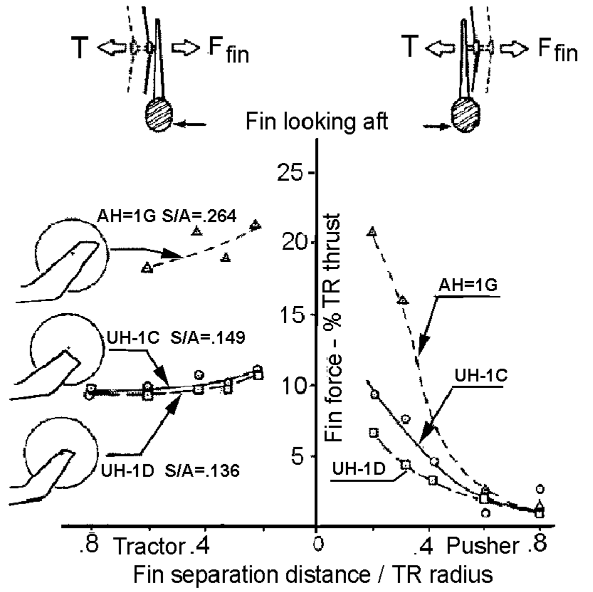

Fig. 1. Fin-tail rotor separation impact on TR thrust loss

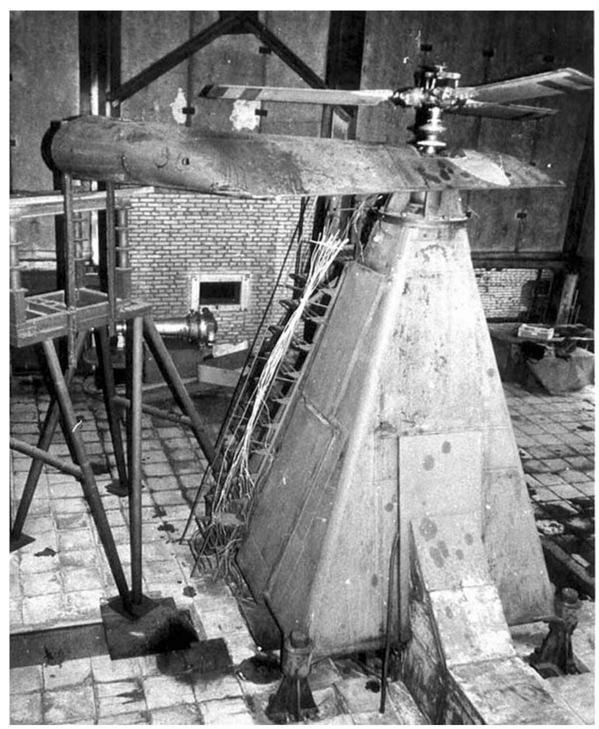

Fig. 2. Mi-24 tail rotor and fin mounted on whirl tower

The TsAGI test rig and its photo are shown in Figs 3 and 4. The tail rotor and fin scale models were installed on the wind tunnel six-component balance so that the forces and moments applied both to the tail rotor and to the fin were measured simultaneously. The tail rotor and fin scale models were installed in such a way that the rotor acted as a pusher relative to the fin.

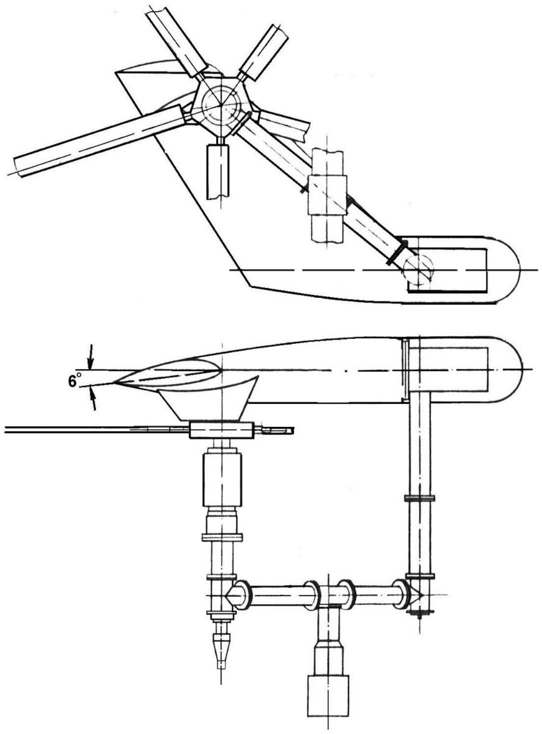

Fig. 3 TR and fin test rig drawing

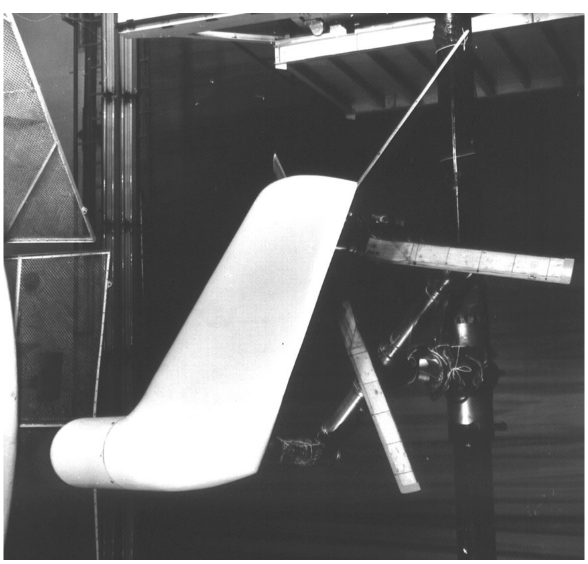

Fig. 4 Test rig of fin-tail rotor interference investigation installed in T-105 wind tunnel

The basic parameters of the tail rotors and the fins tested by the TsAGI and MMHP are shown in Tables 1 and 2.

Table 1. Tail rotor parameters

	D, m	c, m	k	σ
MMHP	3.92	.305	3	.15
TsAGI	1.6	.075	5	.15
	Airfoil	Δφ°	plan form	Tip Mach number
MMHP	NACA-230-12M	0°	rectangular	0.5-0.7
TsAGI	NACA-230-10	0°	rectangular	0.3

Table 2. Fin parameters

	S_{fin} m^2	S_{fin}/A, %	Airfoil
MMHP	2.6	22	RAF-38-20%
TsAGI	.58	23	RAF-38-20%
	Θ $°_{fin}$	Z_{fin}/R	
MMHP	6°	0.35	
TsAGI	6°	0.35	

The tests were carried out for the tail rotor operating both as the tractor producing upward thrust and as the pusher producing downward thrust because tail rotors on Mil helicopters are used in both configurations. It should be mentioned here that a “tractor” and a “pusher” can be applied to a tail rotor somewhat relatively, as tail rotors operate both at positive blade pitch angles, for instance from 0° to 24° of the tail rotor in question, and at negative pitch ones - from 0° to –10°. And while the tail rotor operates as a tractor at positive pitch it operates as a pusher at negative pitch, and vice versa.

Therefore the “tractor” and “pusher” in this paper mean the rotor, whose thrust direction corresponds to the TR pitch range from 0° to 24°.

Comment on the fin-tail rotor interference problem

Before analysing the test results let us remember how the average rotor disk induced velocity varies along the rotor axis in hover.

The diagrams of the induced velocity distribution along the rotor axis according to the momentum theory and actual tests are shown in Fig 5. The diagram is taken from Ref. 2.

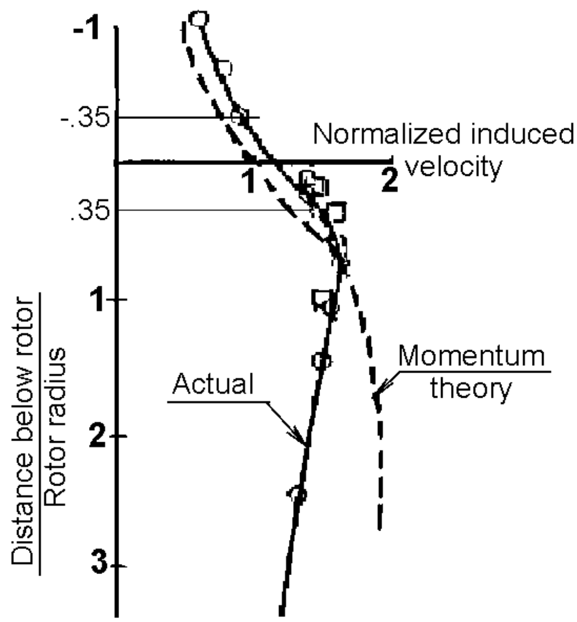

Fig. 5 Induced velocity distribution along rotor axis

Here the rotor radius is laid off along the vertical axis and the induced velocity average over the disk area is laid off along the x-axis.

The distance marked on the graph and equal to **h**=0.35R corresponds to the separation distance between the tail rotor plane of rotation and the longitudinal axis of the fin in the tests being discussed. It is easy to note that at that point the induced velocity equals 1.0 (according to the experiment), while under the rotor plane the induced velocity is 1.5 times higher. Respectively, the side load of the fin located in front of the tail rotor is less than that of the fin located behind the tail rotor. Therefore, it is quite logically to expect that the impact of the fin located in front of a pusher rotor on the rotor is less than that of the fin located behind the rotor operating as a tractor and throwing its wake away onto the fin.

Fin impact on rotor polars

The polar of the tractor rotor (thrust is directed upward at positive pitches) operating separately and the polar of one operating in presence of the fin are compared in Fig.6. The same comparison made for the pusher rotor (thrust is directed downward at positive pitch) is shown in Fig. 7.

Tests were conducted at the tail rotor blade tip speed corresponding to Mach numbers 0.5, 0.6, 0.65 and 0.7. Dependencies obtained from the tests are the same for all Mach numbers examined, in a quality sense, therefore, to cut the story short, the issues discussed will mainly be illustrated by the test results at M=0.65 as this number corresponds to the blade tip speed of the helicopter tail rotor.

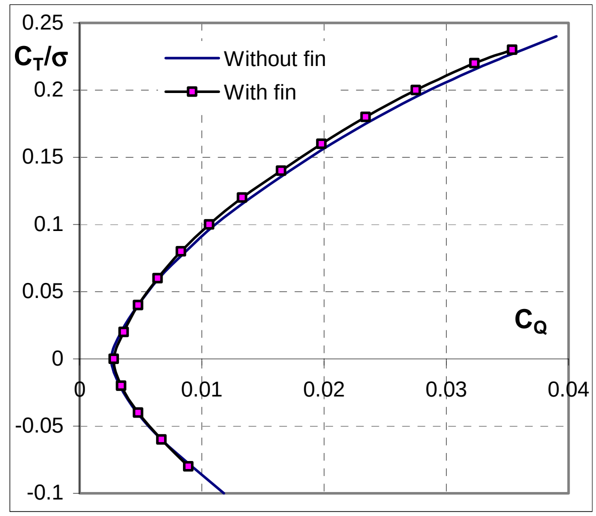

Fig. 6. Tractor rotor polars

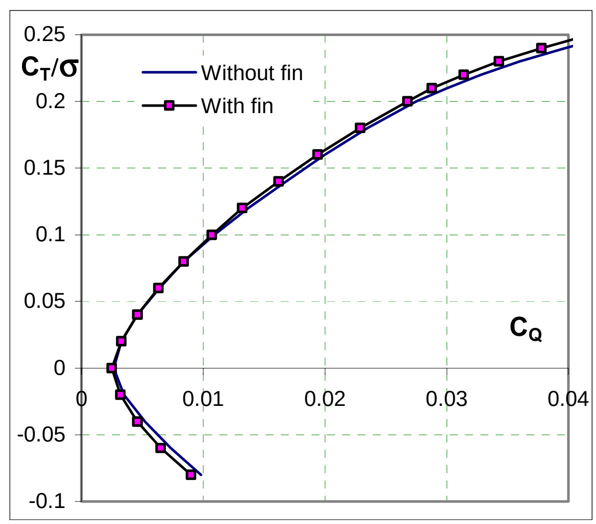

Fig. 7. Pusher rotor polars

The comparison of the tractor rotor polars presented in Fig. 6 shows that there is some improvement of the rotor performance in the positive pitch range and, thus, at positive thrust coefficient C_T/σ when the tail rotor wake strikes the fin.

This improvement becomes apparent from an increase in the C_T/σ thrust coefficient at the constant torque coefficient C_Q or from a decrease in the torque coefficient at the constant thrust coefficient. In the range of negative pitch where the rotor operates as a pusher, i.e. it sucks air from the fin, the polar of an isolated rotor practically coincides with that of the rotor operating in presence of the fin. In a quality sense, the result obtained coincides with the comment made above while considering the induced velocity distribution along the rotor axis that the impact of the fin located under the rotor should be stronger.

The quantitative estimation of the fin impact on the TR performance is of much greater interest than the qualitative one. The coefficient of the fin impact on the tail rotor polar - C_{CQ} is calculated as the difference between the torque coefficient of the rotor operating in presence of the fin - C_{Qfin} and that of the isolated rotor - C_Q divided by the torque coefficient C_Q of the isolated rotor at the constant thrust coefficient.

$$C_{CQ} = \frac{C_{Qfin} - C_Q}{C_Q} 100\%$$

The results of the quantitative estimation for the tractor rotor are given in Fig. 8.

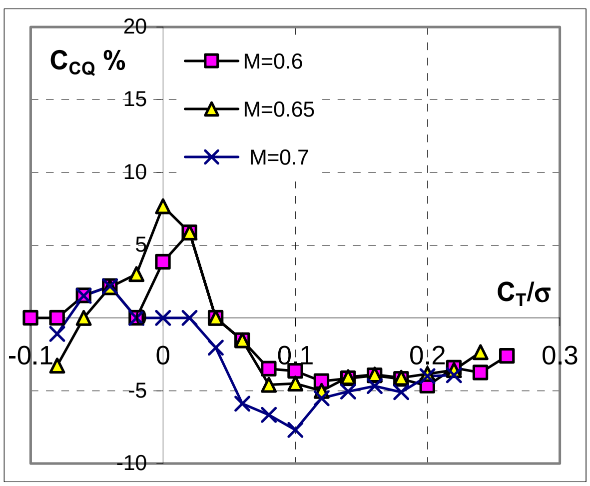

Fig. 8. Estimation of fin impact on tractor rotor polar

It can easily be noted that quite a stable impact of the fin on the tractor rotor polar can be seen for the thrust coefficients $C_T/\sigma \geq 0.12$. However, the fin impact coefficient C_{CQ} amounts to 3-5%. The coefficient C_{CQ} is very unstable in the range of small and negative values of the thrust coefficient C_T/σ. The above instability can be attributed to the insufficient precision of thrust and torque measurements at their small values as well as to the fact that the small difference of torque coefficients C_Q in this range of C_T/σ is comparable with the torque coefficient itself. So, even small absolute measurement errors can lead to quite large relative ones.

The same effect can be seen from the comparison of the pusher rotor polars (Fig. 7). Some improvements of the performance of the rotor operating in presence of the fin can be noted too, i.e. a decrease in the torque coefficient C_Q at the constant thrust coefficient C_T/σ.

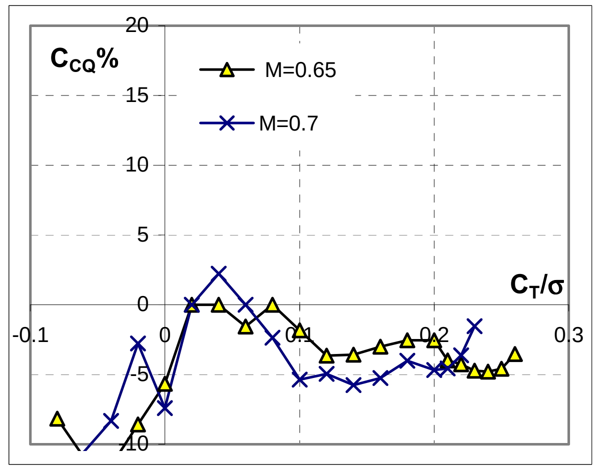

Fig. 9. Estimation of the fin impact on pusher rotor polar

As can be seen from Fig. 9 the fin impact coefficient C_{CQ} amounts to 2-5% at the thrust coefficients $C_T/\sigma \geq 0.1$. Unlike the tractor rotor polars that practically coincided at the negative C_T/σ, the pusher rotor polars separate within the same range of the thrust coefficient, i.e. where the rotor operates as a tractor. This fact also complies with the remark made above that the impact of the fin located under the rotor on the rotor performance should be stronger than that of the fin located above the rotor.

The registered change of the tail rotor performance caused by the airflow around the surface of the fin substantiates the conclusion that can be made proceeding from consideration of the tail rotor-fin interference on the basis of the momentum theory. The fin located near the tail rotor acts as a shield slowing down the induced wake on the part of the rotor disk irrespective of the shield location, either in front of or behind the rotor.

From consideration of the velocity triangle at the blade airfoil in hover shown in Fig. 10, one can see that a decrease in the induced velocity v_i results in an increase in the blade angle of attack, and respectively in an increase in the airfoil lift coefficient C_l and, thus, in the rotor thrust coefficient C_T/σ.

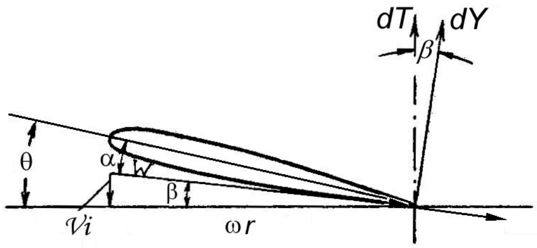

Fig. 10. Velocities and forces at blade airfoil

The same conclusion can be made proceeding from the wake pressure distribution above and under the rotor (Fig. 11).

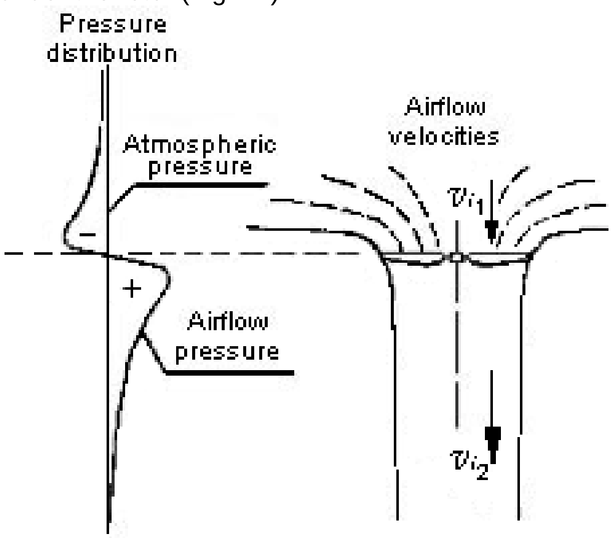

Fig. 11. Wake pressure distribution along the rotor axis

As it was mentioned above, the fin located in the wake behind the rotor produces higher pressure on the part of the rotor disk resulting in an increase in the pressure differential in the rotor plane and, thus, in the rotor thrust. If the fin is located within the wake in front of the rotor, the negative pressure is produced on the fin side adjacent to the rotor, which causes an increase in the pressure differential in the rotor plane, too.

Fin impact on $C_T/\sigma(\varphi)$

Now let us consider the rotor thrust coefficient versus the rotor blade pitch $C_T/\sigma(\varphi)$ obtained from the tests of the rotors operating both separately and in presence of the fin.

The $C_T/\sigma(\varphi)$ dependencies of the tractor tail rotor operating separately and in presence of the fin are shown in Fig. 12. Fig. 13 shows similar dependencies for the pusher tail rotor.

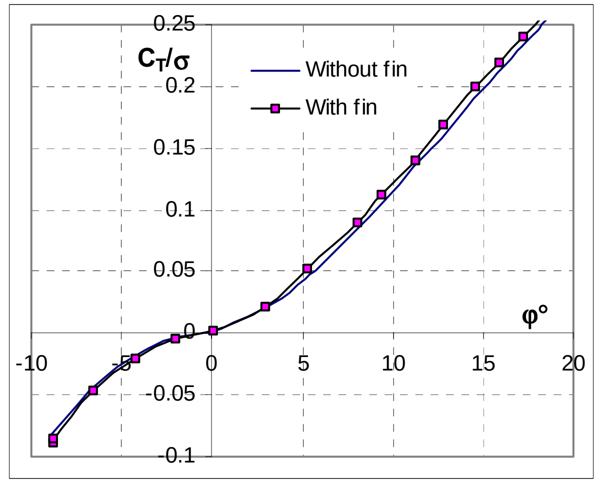

Fig 12. Tractor TR thrust coefficient vs. blade pitch

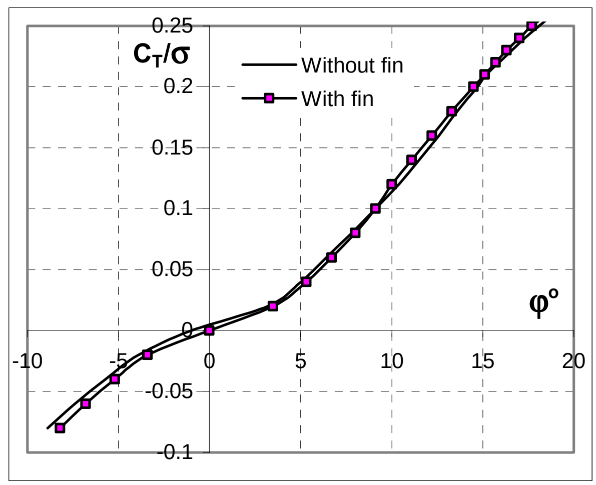

Fig 13. Pusher TR thrust coefficient vs. blade pitch

As can be seen, the fin located within the tail rotor wake exerts some positive influence on the tail rotor performance that can be noted in a slight increase in the thrust coefficient C_T/σ at constant blade pitch within the range of both positive and negative pitch.

The same results were obtained from the tests of the model rotor and fin carried out by V.N.Yakubovich and V.A.Zhabin (TsAGI).

Tests were conducted at the tail rotor RPM corresponding to the blade tip Mach number M=0.3. The polar of an isolated rotor and that of the rotor operating as a pusher in presence of the fin are shown in Fig. 14.

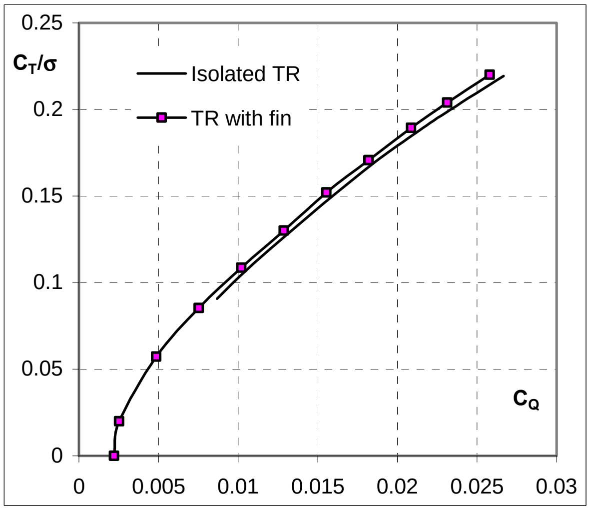

Fig. 14. Polars of the pusher rotor operating with and without fin

The comparison of the results obtained from the tests of the rotor and fin scale models with those obtained by the MMHP shows that they closely agree both in a quality and quantity sense. The fin located in front of the rotor and thus acting as the rotor shield improves the tail rotor performance. The decrease of the torque is about 4 - 5% for the thrust coefficients $C_T/\sigma \geq 0.1$.

Measurements of the thrust and torque of the tail rotor working in presence of the fin were made simultaneously with the measurements of the fin side load caused by the tail rotor wake.

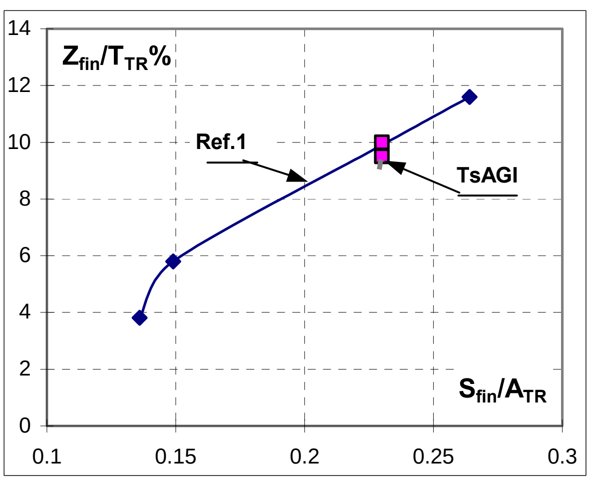

Fig. 15. Fin side load relative to TR thrust

The fin side load obtained from the tested configuration of the tail rotor-fin scale model where the rotor worked as a pusher equals 9.5-10% of the tail rotor thrust. This result is in good agreement with those obtained from the test conducted by Linn R.R. at al (Ref. 1).

The conclusion drawn up by the TsAGI and MMHP on the impact of the fin on the tail rotor performance is different from the short remark made in Linn's paper (Ref. 1) with respect to the pusher tail rotor, that its efficiency loss is experienced due to fin blockage of the airflow in front of the rotor. This remark was, apparently, speculative, as there was nothing in the paper about the experiments conducted to determine the fin impact on the tail rotor performance. The test results discussed in this paper allow us to make an opposite conclusion. The fin exerts a weak but positive influence on the pusher tail rotor performance.

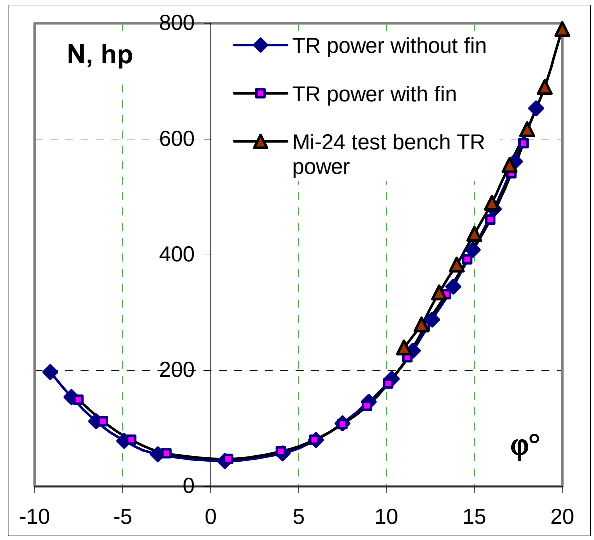

Fig. 16 Tail rotor power required obtained from Mi-24 full-scale bench and whirl tower tests

Finally, the tail rotor power required vs. blade pitch obtained in the present tests was compared with the results of measurements of the tail rotor power required made on the Mi-24 full-scale test bench. Fig. 16 shows this comparison.

As can be seen from the figure, the power required by the tractor tail rotor operating in presence of the fin obtained in the above tests is in good agreement with the measurements of the power required made on the Mi-24 full-scale test bench.

Conclusion

1. The vertical fin located within the tail rotor wake exerts a weak but positive impact on the tail rotor performances. This impact, in a quality sense, is the same for the rotors operating both as a tractor and a pusher.

2. The change in the polar of the rotor operating in presence of the vertical fin that appears as a decrease in torque at constant thrust (or as an increase in thrust at constant torque) is less than 5%.

3. The obtained improvement of the tail rotor performance operating in presence of the fin does not change the conclusion made in Ref 1. The layout of the fin-tail rotor unit where the tail rotor works as a pusher and the tail rotor-fin separation distance is **h** ≥ 0.2R is much more preferable from the point of view of lower tail rotor thrust and torque losses.

References

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2. J.M. Drees, "Prepare for the 21st Century - The 1987 Alexander A. Nicolsky Lecture", presented at the 43rd Annual Forum of the AHS, May, 1987