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Some Results on Subclasses of Multivalent and Meromorphic Functions Defined by Multiplier Transformations

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Abstract

The objective of the present work is to investigate a specific family of uniformly meromorphic of multivalent functions defined in $\mathbb{U}^*$ associated with multiplier transformations. We get some results for this class, like, coefficient estimates, distortion theorem, closure theorem and radii of starlike.

1. Introduction

Assume that $\mho_{\mathfrak{e}}$ be the family of functions that take the following type:

$$\mathbb{J}(\mathfrak{y}) = q_0\mathfrak{y}^{-\mathfrak{e}} + \sum_{n=1-\mathfrak{e}}^{\infty} q_n\mathfrak{y}^n \, q_0 > 0, \quad q_n \geq 0, \, \mathfrak{e} \in N = \{1,2,\dots\}, \tag{1}$$

that are multivalent meromorphic in $\mathbb{U}^* = \{\mathfrak{y} \in \mathbb{C}, 0 < |\mathfrak{y}| < 1\} = U/\{0\}$.

For $n \in \mathbb{Z}$, $\ell > 0, \mathfrak{X} \geq 0$ and $\mathbb{J} \in \mho_{\mathfrak{e}}$, the multiplier transformations $\mathfrak{L}_{\mathfrak{e}}^m(\ell,\mathfrak{X}) : \mho_{\mathfrak{e}} \longrightarrow \mho_{\mathfrak{e}}$ is defined by (see [4])

$$\mathfrak{L}_{\mathfrak{e}}^m(\ell,\mathfrak{X})\mathbb{J}(\mathfrak{y}) = q_0\mathfrak{y}^{-\mathfrak{e}} + \sum_{n=1-\mathfrak{e}}^{\infty} \left(\frac{\left(\ell + \mathfrak{X}(n+\mathfrak{e})\right)}{\ell}\right)^m q_n\mathfrak{y}^n \, . \tag{2}$$

A function $\mathbb{J} \in \mho_{\mathfrak{e}}$ is named multivalent meromorphic starlike function of order α whenever it satisfies the condition

$$-Re\left\{\frac{\mathfrak{y}\,\mathbb{J}'(\mathfrak{y})}{\mathbb{J}(\mathfrak{y})}\right\} > \alpha \,, \qquad (\mathfrak{y} \in \mathbb{U}^*; \quad 0 \leq \alpha < \mathfrak{e}), \tag{3}$$

and is named multivalent meromorphic convex functions of order α whenever it satisfies the condition

$$-Re\left\{\frac{\mathfrak{y}\,\mathbb{J}''(\mathfrak{y})}{\mathbb{J}'(\mathfrak{y})} + 1\right\} > \alpha \,, \qquad (\mathfrak{y} \in \mathbb{U}^*; \quad 0 \leq \alpha < \mathfrak{e}). \tag{4}$$

We define $G(x,\ell,\mathfrak{X},m,\mathfrak{e})$ as the family of functions in $\mho_{\mathfrak{e}}$ that fulfill the condition stated below:

$$Re\left\{-\left(\frac{\mathfrak{y}\left(\mathfrak{L}_{\mathfrak{e}}^m(\ell,\mathfrak{X})\mathbb{J}(\mathfrak{y})\right)''}{(1+\mathfrak{e})\left(\mathfrak{L}_{\mathfrak{e}}^m(\ell,\mathfrak{X})\mathbb{J}(\mathfrak{y})\right)'} + x\right)\right\} \geq \left|\frac{\mathfrak{y}\left(\mathfrak{L}_{\mathfrak{e}}^m(\ell,\mathfrak{X})\mathbb{J}(\mathfrak{y})\right)''}{(1+\mathfrak{e})\left(\mathfrak{L}_{\mathfrak{e}}^m(\ell,\mathfrak{X})\mathbb{J}(\mathfrak{y})\right)'} + x + 2\right|, \tag{5}$$

where $0 < x < 1, n \in \mathbb{Z}, \ell > 0, \mathfrak{X} \geq 0$.

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A number of studies have lately focused on analyzing subclasses of meromorphic functions, as documented in references [1,2,3,5,6,7,8,9,10].

2. Coefficient Estimates

Theorem 1. *Let* $\mathbb{J} \in \mho_{e}$. *Then* $\mathbb{J} \in G(x, \ell, \mathfrak{X}, m, e)$, *iff*

$$\sum_{n=1-e}^{\infty} n[(e+1)(x+1)+(n-1)]\left(\frac{(\ell+\mathfrak{X}(n+e))}{\ell}\right)^{m} q_{n} \leq q_{0} e(e+1)x. \tag{6}$$

Sharpness of the result is attained for the function $\mathbb{J}$ *described as*

$$\mathbb{J}(\mathfrak{y}) = q_0 \mathfrak{y}^{-e} + \frac{q_0 e(e+1)x}{n[(e+1)(x+1)+(n-1)]\left(\frac{(\ell+\mathfrak{X}(n+e))}{\ell}\right)^{m}} \mathfrak{y}^{1-e}, \quad n \geq 1-e. \tag{7}$$

Proof. Suppose that $\mathbb{J} \in G(x, \ell, \mathfrak{X}, m, e)$. Then

$$Re\left\{-\left(\frac{\mathfrak{y}\left(\mathfrak{L}_{e}^{m}(\ell,\mathfrak{X})\mathbb{J}(\mathfrak{y})\right)''}{(e+1)\left(\mathfrak{L}_{e}^{m}(\ell,\mathfrak{X})\mathbb{J}(\mathfrak{y})\right)'}+x\right)\right\} \geq \left|\frac{\mathfrak{y}\left(\mathfrak{L}_{e}^{m}(\ell,\mathfrak{X})\mathbb{J}(\mathfrak{y})\right)''}{(e+1)\left(\mathfrak{L}_{e}^{m}(\ell,\mathfrak{X})\mathbb{J}(\mathfrak{y})\right)'}+x+2\right|.$$

But

$$Re\left\{\frac{\mathfrak{y}\left(\mathfrak{L}_{e}^{m}(\ell,\mathfrak{X})\mathbb{J}(\mathfrak{y})\right)''}{(e+1)\left(\mathfrak{L}_{e}^{m}(\ell,\mathfrak{X})\mathbb{J}(\mathfrak{y})\right)'}+x\right\} \leq \left|\frac{\mathfrak{y}\left(\mathfrak{L}_{e}^{m}(\ell,\mathfrak{X})\mathbb{J}(\mathfrak{y})\right)''}{(e+1)\left(\mathfrak{L}_{e}^{m}(\ell,\mathfrak{X})\mathbb{J}(\mathfrak{y})\right)'}+x+2\right|$$
$$\leq Re\left\{-\left(\frac{\mathfrak{y}\left(\mathfrak{L}_{e}^{m}(\ell,\mathfrak{X})\mathbb{J}(\mathfrak{y})\right)''}{(1+e)\left(\mathfrak{L}_{e}^{m}(\ell,\mathfrak{X})\mathbb{J}(\mathfrak{y})\right)'}+x\right)\right\},$$

that is

$$Re\left\{\frac{\mathfrak{y}\left(\mathfrak{L}_{e}^{m}(\ell,\mathfrak{X})\mathbb{J}(\mathfrak{y})\right)''}{(1+e)\left(\mathfrak{L}_{e}^{m}(\ell,\mathfrak{X})\mathbb{J}(\mathfrak{y})\right)'}+2(x+1)\right\} \leq 0,$$

by (2) we get

$$\sum_{n=1-e}^{\infty} n[(e+1)(x+1)+(n-1)]\left(\frac{(\ell+\mathfrak{X}(n+e))}{\ell}\right)^{m} q_{n} \leq q_{0} e(e+1)x$$

$$Re\left\{\frac{-2e(e+1)x q_0 \mathfrak{y}^{-e-1} + \sum_{n=1-e}^{\infty} 2n[(n-1)+(e+1)(x+1)]\left(\frac{(\ell+\mathfrak{X}(n+e))}{\ell}\right)^{m} q_n \mathfrak{y}^{n-1}}{-e q_0 (e+1)\mathfrak{y}^{-e-1} + \sum_{n=1-e}^{\infty} n(e+1)\left(\frac{(\ell+\mathfrak{X}(n+e))}{\ell}\right)^{m} q_n \mathfrak{y}^{n-1}}\right\} \leq 0.$$

Letting $\mathfrak{y}$ to take real values as $\mathfrak{y} \to 1^{-}$, we get

$$\frac{-2e(e+1)x q_0 + \sum_{n=1-e}^{\infty} 2n[(n-1)+(e+1)(x+1)]\left(\frac{(\ell+\mathfrak{X}(n+e))}{\ell}\right)^{m} q_n}{-e q_0 (e+1) + \sum_{n=1-e}^{\infty} n(e+1)\left(\frac{(\ell+\mathfrak{X}(n+e))}{\ell}\right)^{m} q_n} \leq 0,$$

that is

$$-2\mathrm{e}(\mathrm{e}+1)x q_0+\sum_{n=1-\mathrm{e}}^{\infty}2n[(n-1)+(\mathrm{e}+1)(x+1)]\left(\frac{(\ell+\mathfrak{X}(n+\mathrm{e}))}{\ell}\right)^m q_n\le 0,$$

which is equivalent to (6).

On the other hand, if we assume that inequality (6) holds, we deduce that

$$\left|\frac{\mathfrak{y}\left(\mathfrak{L}_{\mathrm{e}}^{m}(\ell,\mathfrak{X})\mathbb{J}(\mathfrak{y})\right)''}{(\mathrm{e}+1)\left(\mathfrak{L}_{\mathrm{e}}^{m}(\ell,\mathfrak{X})\mathbb{J}(\mathfrak{y})\right)'}+x+2\right|=\left|\frac{\begin{array}{c}-2\mathrm{e}(\mathrm{e}+1)(x+2)q_0\,\mathfrak{y}^{-\mathrm{e}-1}\\ +\sum_{n=1-\mathrm{e}}^{\infty}n\left[2(n-1)+(x+2)(\mathrm{e}+1)\left(\frac{(\ell+\mathfrak{X}(n+\mathrm{e}))}{\ell}\right)^m\right]q_n\mathfrak{y}^{n-1}\end{array}}{-\mathrm{e}q_0(\mathrm{e}+1)\mathfrak{y}^{-\mathrm{e}-1}+\sum_{n=1-\mathrm{e}}^{\infty}n(\mathrm{e}+1)\left(\frac{(\ell+\mathfrak{X}(n+\mathrm{e}))}{\ell}\right)^m q_n\mathfrak{y}^{n-1}}\right|$$

$$\le\frac{\begin{array}{c}-2\mathrm{e}(\mathrm{e}+1)(x+2)q_0\\ -\sum_{n=1-\mathrm{e}}^{\infty}n\left[2(n-1)+(x+2)(\mathrm{e}+1)\left(\frac{(\ell+\mathfrak{X}(n+\mathrm{e}))}{\ell}\right)^m\right]q_n\mathfrak{y}^{n+\mathrm{e}}\end{array}}{-\mathrm{e}q_0(\mathrm{e}+1)+\sum_{n=1-\mathrm{e}}^{\infty}n(\mathrm{e}+1)\left(\frac{(\ell+\mathfrak{X}(n+\mathrm{e}))}{\ell}\right)^m q_n\mathfrak{y}^{n+\mathrm{e}}}.$$

Taking the limit as $\mathfrak{y}\to 1^-$ along the real axis yields the required inequality (6). Therefore, the proof of Theorem 1 is established.

Corollary 1. *If* $\mathbb{J}\in G(x,\ell,\mathfrak{X},m,\mathrm{e})$, *then*

$$q_n\le\frac{\mathrm{e}(\mathrm{e}+1)x q_0}{n[(n-1)+(\mathrm{e}+1)(x+1)]\left(\frac{(\ell+\mathfrak{X}(n+\mathrm{e}))}{\ell}\right)^m}\quad (n,\mathrm{e}\in N=\{1,2,\dots\}).\tag{8}$$

Theorem 2. *Let* $\mathbb{J}\in G(x,\ell,\mathfrak{X},m,\mathrm{e})$. *Then*

$$\frac{q_0}{r^{\mathrm{e}}}-\frac{\mathrm{e}(\mathrm{e}+1)x}{(1-\mathrm{e})[-\mathrm{e}+(\mathrm{e}+1)(x+1)]\left(\frac{\ell+\mathfrak{X}}{\ell}\right)^m}r^{1-\mathrm{e}}\le|\mathbb{J}(\mathfrak{y})|\le\frac{q_0}{r^{\mathrm{e}}}+\frac{\mathrm{e}(\mathrm{e}+1)x}{(1-\mathrm{e})[-\mathrm{e}+(\mathrm{e}+1)(x+1)]\left(\frac{\ell+\mathfrak{X}}{\ell}\right)^m}r^{1-\mathrm{e}}.$$

Proof. Since $\mathbb{J}\in G(x,\ell,\mathfrak{X},m,\mathrm{e})$, we get

$$(1-\mathrm{e})[-\mathrm{e}+(\mathrm{e}+1)(x+1)]\left(\frac{\ell+\mathfrak{X}}{\ell}\right)^m\sum_{n=1-\mathrm{e}}^{\infty}q_n$$
$$\le\sum_{n=1-\mathrm{e}}^{\infty}n[(n-1)+(\mathrm{e}+1)(x+1)]\left(\frac{(\ell+\mathfrak{X}(n+\mathrm{e}))}{\ell}\right)^m q_n\le\mathrm{e}(\mathrm{e}+1)x.$$

We have

$$|\mathbb{J}(\mathfrak{y})|=\frac{q_0}{|\mathfrak{y}|^{\mathrm{e}}}+\sum_{n=1-\mathrm{e}}^{\infty}q_n|\mathfrak{y}|^n\le\frac{q_0}{|\mathfrak{y}|^{\mathrm{e}}}+|\mathfrak{y}|^{1-\mathrm{e}}\sum_{n=1-\mathrm{e}}^{\infty}q_n\le\frac{q_0}{r^{\mathrm{e}}}+\frac{\mathrm{e}(\mathrm{e}+1)x}{(1-\mathrm{e})[-\mathrm{e}+(\mathrm{e}+1)(x+1)]\left(\frac{\ell+\mathfrak{X}}{\ell}\right)^m}r^{1-\mathrm{e}}.$$

Also, similarly, we have

$$|\mathbb{J}(\mathfrak{y})|\ge\frac{q_0}{r^{\mathrm{e}}}-\frac{\mathrm{e}(\mathrm{e}+1)x}{(1-\mathrm{e})[-\mathrm{e}+(\mathrm{e}+1)(x+1)]\left(\frac{\ell+\mathfrak{X}}{\ell}\right)^m}r^{1-\mathrm{e}}.$$

Sharpness of the result is attained for the function $\mathbb{J}$ described as

$$\mathbb{J}(\mathfrak{y}) = q_0 \mathfrak{y}^{-e} + \frac{q_0 e(e+1)x}{(1-e)[-e+(e+1)(x+1)]\left(\frac{\ell+\mathfrak{X}}{\ell}\right)^m} \mathfrak{y}^{1-e}, \quad e \in N.$$

Now, let us consider the functions $\mathbb{J}_j(\mathfrak{y})$, defined for $j = 1,2,\ldots,q$, by

$$\mathbb{J}_j(\mathfrak{y}) = q_{0,j}\mathfrak{y}^{-e} + \sum_{n=1-e}^{\infty} q_{n,j}\mathfrak{y}^n \quad \left(q_{0,j} > 0, q_{n,j} \geq 0, e \in N = \{1,2,\ldots\}\right). \tag{9}$$

Theorem 3. *Assume that the functions* $\mathbb{J}_j(\mathfrak{y})$ *defined by* (9) *lies in the family* $G(x,\ell,\mathfrak{X},m,e)$ *for* $j = 1,2,\ldots,q$. *Then the function* $h(\mathfrak{y})$ *defined as*

$$h(\mathfrak{y}) = q_{0,j}\mathfrak{y}^{-e} + \sum_{n=1-e}^{\infty} c_n \mathfrak{y}^n$$

is also in the family $G(x,\ell,\mathfrak{X},m,e)$, *where*

$$c_n = \frac{1}{q}\sum_{j=1}^{q} q_{n,j}.$$

Proof. Since $\mathbb{J}_j(\mathfrak{y}) \in G(x,\ell,\mathfrak{X},m,e)$ $(j = 1,2,\ldots,q)$ and by Theorem 1, we obtain

$$\sum_{n=1-e}^{\infty} n[(n-1)+(e+1)(x+1)]\left(\frac{\left(\ell+\mathfrak{X}(n+e)\right)}{\ell}\right)^m q_{n,j} \leq e(e+1)x.$$

Hence

$$\begin{aligned}
&\sum_{n=1-e}^{\infty} n[(n-1)+(e+1)(x+1)]\left(\frac{\left(\ell+\mathfrak{X}(n+e)\right)}{\ell}\right)^m c_n \\
&\quad = \sum_{n=1-e}^{\infty} n[(n-1)+(e+1)(x+1)]\left(\frac{\left(\ell+\mathfrak{X}(n+e)\right)}{\ell}\right)^m \left(\frac{1}{q}\sum_{j=1}^{q} q_{n,j}\right) \\
&\quad = \frac{1}{q}\sum_{j=1}^{q} \sum_{n=1-e}^{\infty} n[(n-1)+(e+1)(x+1)]\left(\frac{\left(\ell+\mathfrak{X}(n+e)\right)}{\ell}\right)^m q_{n,j} \leq e(e+1)x.
\end{aligned}$$

This shows that $h(\mathfrak{y}) \in G(x,\ell,\mathfrak{X},m,e)$.

Theorem 4. *Let* $\mathbb{J}$ *be an element of* $G(x,\ell,\mathfrak{X},m,e)$. *Then* $\mathbb{J}$ *is multivalent meromorphic starlike of order* $\varphi(0 \leq \varphi < 1)$ *in the region* $|\mathfrak{y}| < R_1$ *such that*

$$R_1 = \inf_n \left\{\frac{n(e-\varphi)[(e+1)(x+1)+(n-1)]\left(\frac{\left(\ell+\mathfrak{X}(n+e)\right)}{\ell}\right)^m}{e(e+1)x(n+\varphi)}\right\}^{\frac{1}{n-e}}.$$

The obtained result is exact for the function $\mathbb{J}$ *defined in* (7).

Proof. It is enough to demonstrate that

$$\left|\frac{\mathfrak{y}\mathbb{J}'(\mathfrak{y})}{\mathbb{J}(\mathfrak{y})}+\mathrm{e}\right| \le \mathrm{e}-\varphi \quad \text{for } |\mathfrak{y}|<R_1. \tag{10}$$

But

$$\left|\frac{\mathfrak{y}\mathbb{J}'(\mathfrak{y})}{\mathbb{J}(\mathfrak{y})}+\mathrm{e}\right| = \left|\frac{\mathfrak{y}\mathbb{J}'(\mathfrak{y})+\mathrm{e}\mathbb{J}(\mathfrak{y})}{\mathbb{J}(\mathfrak{y})}\right| \le \frac{\sum_{n=1-\mathrm{e}}^{\infty}(n+\mathrm{e})q_n|\mathfrak{y}|^{n-\mathrm{e}}}{1+\sum_{n=1-\mathrm{e}}^{\infty}q_n|\mathfrak{y}|^{n-\mathrm{e}}}.$$

Thus (10) will be satisfied if

$$\frac{\sum_{n=1-\mathrm{e}}^{\infty}(n+\mathrm{e})q_n|\mathfrak{y}|^{n-\mathrm{e}}}{q_0+\sum_{n=1-\mathrm{e}}^{\infty}q_n|\mathfrak{y}|^{n-\mathrm{e}}} \le \mathrm{e}-\varphi,$$

or if

$$\sum_{n=1-\mathrm{e}}^{\infty}\frac{n+\varphi}{q_0(\mathrm{e}-\varphi)}q_n|\mathfrak{y}|^{n-\mathrm{e}} \le 1. \tag{11}$$

Since $\mathbb{J} \in G(x,\ell,\mathfrak{X},m,\mathrm{e})$, we have

$$\sum_{n=1-\mathrm{e}}^{\infty}\frac{n[(\mathrm{e}+1)(x+1)+(n-1)]\left(\frac{(\ell+\mathfrak{X}(n+\mathrm{e}))}{\ell}\right)^m}{q_0\mathrm{e}(\mathrm{e}+1)x}q_n \le 1.$$

Hence (11) will be true if

$$\frac{n+\varphi}{q_0(\mathrm{e}-\varphi)}|\mathfrak{y}|^{n-\mathrm{e}} \le \frac{n[(\mathrm{e}+1)(x+1)+(n-1)]\left(\frac{(\ell+\mathfrak{X}(n+\mathrm{e}))}{\ell}\right)^m}{q_0\mathrm{e}(\mathrm{e}+1)x},$$

or equivalently

$$|\mathfrak{y}| \le \left\{\frac{n(\mathrm{e}-\varphi)[(\mathrm{e}+1)(x+1)+(n-1)]\left(\frac{(\ell+\mathfrak{X}(n+\mathrm{e}))}{\ell}\right)^m}{\mathrm{e}(\mathrm{e}+1)x(n+\varphi)}\right\}^{\frac{1}{n-\mathrm{e}}} \quad (n \ge 1-\mathrm{e}),$$

which is an immediate consequence of the result.

Theorem 5. *The family* $G(x,\ell,\mathfrak{X},m,\mathrm{e})$ *is a convex set*.

Proof. Consider $\mathbb{J}_1$ and $\mathbb{J}_2$ as arbitrary elements of $G(x,\ell,\mathfrak{X},m,\mathrm{e})$. Then for each t $(0 \le t \le 1)$, we show that $(1-t)\mathbb{J}_1+t\mathbb{J}_2 \in G(x,\ell,\mathfrak{X},m,\mathrm{e})$. Thus, we have

$$(1-t)\mathbb{J}_1+t\mathbb{J}_2 = q_0\mathfrak{y}^{-\mathrm{e}}+\sum_{n=1-\mathrm{e}}^{\infty}[(1-t)q_n+tp_n]\mathfrak{y}^n\,.$$

Hence

$$\sum_{n=1-\mathrm{e}}^{\infty}n[(\mathrm{e}+1)(x+1)+(n-1)]\left(\frac{(\ell+\mathfrak{X}(n+\mathrm{e}))}{\ell}\right)^m[(1-t)q_n+tp_n]$$

$$=(1-t)\sum_{n=1-\mathrm{e}}^{\infty}n[(\mathrm{e}+1)(x+1)+(n-1)]\left(\frac{(\ell+\mathfrak{X}(n+\mathrm{e}))}{\ell}\right)^m q_n$$

$$+ t \sum_{n=1-\mathrm{e}}^{\infty} n[(\mathrm{e}+1)(x+1)+(n-1)] \left(\frac{(\ell + \mathfrak{X}(n+\mathrm{e}))}{\ell}\right)^{m} \wp_n$$

$$\leq (1-t)q_0\mathrm{e}(\mathrm{e}+1)x + tq_0\mathrm{e}(\mathrm{e}+1)x = q_0\mathrm{e}(\mathrm{e}+1)x.$$

Hence, the proof is established.

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